4th Workshop on Climate Variability of the Eastern North Pacific and Western North America

22-26 March 1987
Asilomar Conference Center
Pacific Grove, California

PACLIM

Climate Variability of the Eastern North Pacific and Western North America

The following is information about PACIFIC CLIMATE (PACLIM) activities. As you may know Dr. Chris Mooers is, reluctantly, not able to continue as cochairman of the PACLIM workshop. His past efforts involving considerable time, starting in 1983, and his leadership are appreciated. We are fortunate that Dr. Richard Barber, Director of the Monterey Bay Aquarium Research Institute has kindly agreed to assume the responsibilities of Dr. Mooers.

Plans for the fifth 1988 workshop agenda at Asilomar, Monterey, California, March 20-24 are in preparation. A brief meeting (attended by Richard Barber, Dan Cayan, Jim Gardner, Jurate Landwehr, Mark Meier, David Peterson, Gunnar Roden, Bill Sprigg and Roy Walters) was held at AGU in San Francisco in December, 1987. In addition to the up-coming 1988 workshop the status of the AGU monograph and time series volumes were discussed. Sponsors for the 1988 workshop include the National Science Foundation, Climate Dynamics Program, the Monterey Bay Aquarium Research Institute, and the U.S. Geological Survey. The nature of the AGU monograph and its preparation and publishing schedules have been approved by AGU. By achieving a reasonable turn-around time from the manuscript reviewers, it appears that the volume will be published near the end of 1988, perhaps for distribution at the December AGU.

Enclosed is the 1987 workshop report. Information on the 1988 workshop is forthcoming for those indicating an interest in attending.

Sincerely,

Richard Barber
(signature)

Richard Barber
Director

David Peterson
(signature)

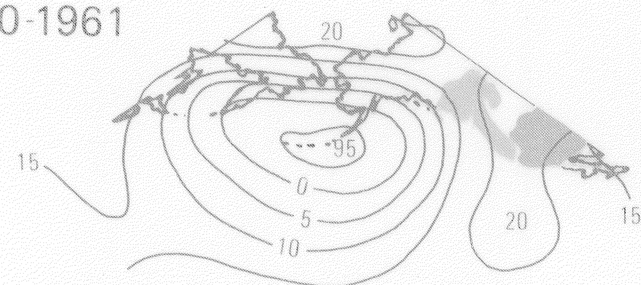
David Peterson

FRONTISPIECE

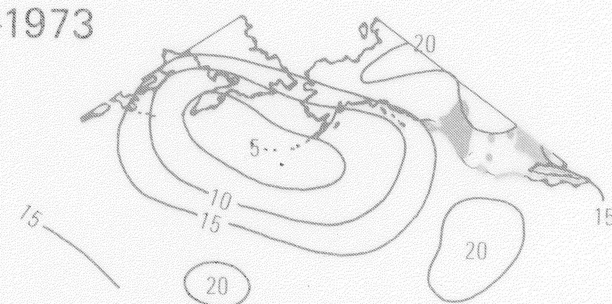
Similar modes of large-scale atmospheric circulation ("stimulation") appear to be associated with similar large-scale spatial patterns of stream flow ("response"). The winter 1960-1961 typifies a strong atmospheric circulation pattern which tends to elicit a wet coastal Alaska and Canada and a dry interior northwestern United States. The winter 1972-1973, a weak atmospheric circulation pattern, shows a reverse stream flow pattern (of the 1960-1961 strong winter pattern). Probably for this reason the Clark Fork River, Montana, a river basin in the interior northwestern United States, tends to be dry in years of strong atmospheric circulation (brown) and wet in years of weak circulation (green). Such patterns raise the question can paleoclimate time series reveal similar wet-dry spatial teleconnections? (From work in progress of D. Cayan, S.I.O.; sea level atmospheric pressure patterns from Namias (1975); stream flow patterns from U.S. Geological Survey).

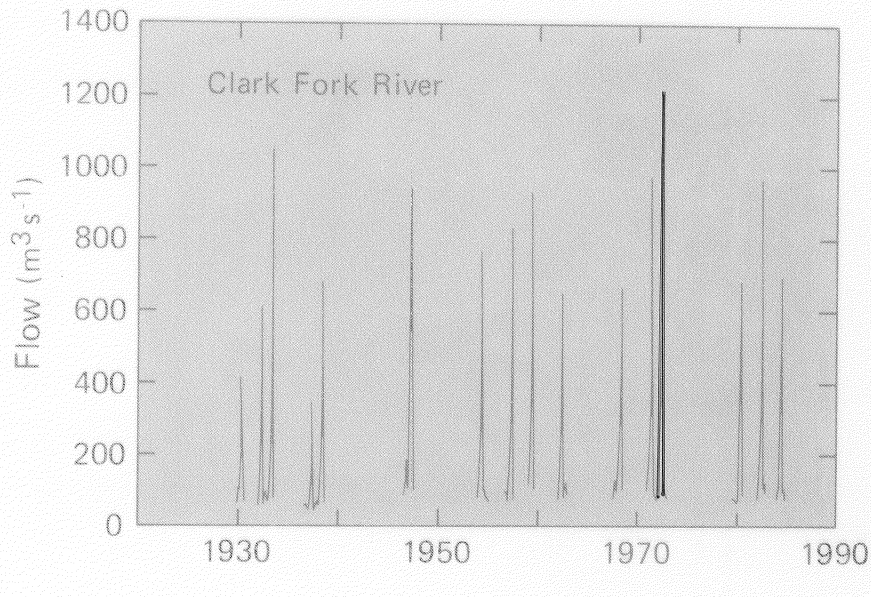
Monthly Streamflow
Winter Sea Level Pressure

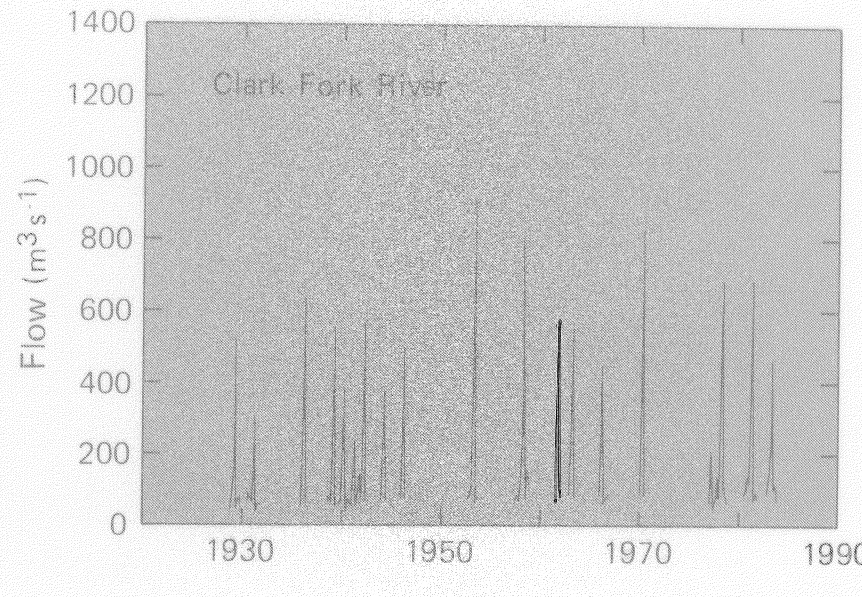
1960-1961



1972-1973







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I. INTRODUCTION

There is broad concern about the impact of possible climatic change over the next century. From observed variations in the historical record, it is certain that the effects of such changes have tremendous societal impacts through coincident effects on global ecology, hydrology, geology and oceanography. Clearly, our ability to predict a change in climate is best derived from an understanding of global processes. Societal impacts are primarily terrestrial in nature, whereas the major forcing processes are atmospheric and oceanic in origin and tempered by biological, geological, and hydrological conditions.

Our understanding of the global climate system and its effects on ecosystems will be enhanced by a regional study of its components in the Pacific Ocean and the western Americas, where the coupling is strongly expressed. With such diverse meteorologic phenomena as El Nino-Southern Oscillation (ENSO) and shifts in the Aleutian Low and North Pacific High, the eastern Pacific is a region that has tremendous global influences, and strong effects on North America, in particular. This region is rich in climatic records, both instrumental and proxy, and recent research efforts are beginning to focus on better paleoclimatic reconstructions that will put present day climatic variability in context and should improve our anticipation of future changes.

The PACLIM workshops have addressed the problem of defining regional coupling of multifold elements, as organized by phenomena that are global in extent. Because climate expresses itself throughout the natural system, our activity has been, from the first, multidisciplinary in scope and is evolving into a truly interdisciplinary cooperative effort. Specialized knowledge from different disciplines has brought together these characteristic climatic records and process measurements to provide a synthesis of understanding of the complete system.

Our interdisciplinary group uses diverse time series records, measured both directly and through proxy indicators, to study past climatic conditions and current processes in this region. Characterizing and linking the geosphere, biosphere and hydrosphere in this region will provide a scientific analogue and, hence, a basis for both understanding similar linkages in other regions and for anticipating the response to future climate variations. Our emphasis in PACLIM is to study the interrelationships among diverse time series, where the resultant information obtained will be complementary and will lead to better synthesis of the biological, geophysical, and hydrological variability in this region. By necessity, in order to understand these interactive phenomena, we will incorporate studies that consider a broad range of topics and multiple time scales, from months to millenia.

PACLIM has provided a forum for communication among those scientists interested in processes represented by instrumental observations and others reconstructing climatic changes from proxy records that represent ecosystem or physical responses to climatic forcing. Only a multidisciplinary effort is likely to provide for a comprehensive reconstruction, given the spottiness of available paleoclimatic information. A growing conviction within the PACLIM group is that a better grasp of the paleoclimate signal will be possible from an understanding of the mechanisms by which these signals are incorporated into various proxy records. Recent attention has been focused on the (ENSO) phenomenon as a bridge that spans the gap between the modern instrumental record and proxy records. Because ENSO leaves a relatively strong imprint upon the natural systems, it is possible to integrate the process studies of physical and biological oceanographers and climatologists in order to better interpret the paleoclimatic record. This integration would provide an important link between modern process-oriented studies and the much longer plaeoclimatic record which normally does not provide sufficient resolution for direct comparison with instrumental observations.

The benefit of the effort to understand the regulation of ecosystems and their variability is clear. It is critical now for both management and for a better scientific grasp of the problems, that we develop a more complete understanding of how climatic changes affects the structure and function of these systems. The PACLIM venue covers a broad range of ecosystem types and richness, allowing for comparative studies. Further, there is strong theoretical support for the idea that complex biological communities can exist in multiple quasi-stable states. These states can be forced to shift from one to another by physical disturbance. However, theory does not tell us which combinations of climatic-physical-chemical changes are most effective in causing transitions from one state to another. Fortunately, there is empirical evidence that large scale climatic fluctuations force large scale marine ecosystem responses in the California current, and in a very different system, the north Pacific central gyre. The implications of these observations indicate the need for an aggressive pursuit of multidisciplinary study.

The water resources in the western Americas exhibits a range of fluctuations over a continuum of scales and has considerable terrestrial influences and social consequences, particularly in the southwest where demand is high relative to uncommitted supply. The spatial extent and variability of the hydrologic system, such as precipitation deficits and drought, are strongly coupled to climate. For instance, in the western United States, where the precipitation is primarily a cool season phenomenon, year-to-year changes in the activity and tracking of north Pacific winter storms have a strong influence on the water balance. In turn, this atmospheric variability is at least weakly coupled to anomalous thermal conditions in the upper ocean. Thus, a primary objective of PACLIM is to better understand the linkage between large scale atmospheric variability and hydrologic variability, with its complex effects on chemical and biological systems.

II. THE FOURTH ANNUAL PACLIM WORKSHOP

Abstracts of Presentations

A RAINFALL CLIMATOLOGICAL INDEX BASED ON PRINCIPAL COMPONENT ANALYSIS OF DATA FROM NEAR-COAST STATIONS IN OREGON AND CALIFORNIA

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ABSTRACT

Principal component analysis was used to produce an environmental index based on rainfall in the near coastal area of Oregon and California. The area was selected because it borders the California Current region which is the subject of fisheries-environmental relationships at the Pacific Fisheries Environmental Group. Only the development of the index was the subject of this paper.

Rainfall for the "water year" over the time span of about 100 years at 17 stations formed the basis for the computation of the index. The data were standardized by subtracting the mean from each annual datum and dividing by the standard deviation. This was done to make all data of comparable relative magnitude and to emphasize the relative change. Principal component analysis produced coefficients which were used to transform the standardized variables into a single new variable which is the linear combination and that accounts for most of the variance of the standardized data. The time series of this proxy variable constitutes the climatological index.

The analysis revealed that the coastal rainfall pattern defined three geographic sub-regions: (1) Corvallis, Oregon, to Eureka, California; (2) Ukiah to Watsonville, California; and (3) San Luis Obispo to San Diego, California. Time series of indexes for each of these were computed as well as one for the overall coastal area. The locations of the boundaries of these indexes is consistent with the patterns of other environmental variables and with ranges of biotic assemblages within the California Current adjacent to corresponding portions of the coast.

Time series plots of the indexes show fluctuations with a duration of about 15 years. There also is apparent a slight general rise to the indexes from the early 1930's to the late 1970's. Coherence among the three sub-regions is apparent in the pattern of the time series plots. Plots of first difference of the indexes were made to detrend the data. These diagrams revealed that in five of six major El Niños that occurred during the span of the time series, the rainfall index changes were extraordinary. El Niños often took place coincidentally with years of large changes in rainfall. The most of these instances rainfall was higher than usual; although a few were lower.

VARIABILITY OF THE LATE PLEISTOCENE-HOLOCENE OXYGEN-MINIMUM ZONE OFF CENTRAL AND NORTHERN CALIFORNIA

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Late Pleistocene-Holocene sediments along the upper continental slope off california, at water depths between 600 and 1,500 m, contain zones of varves alternating with bioturbation that reflect past variations in the intensity of the oxygen minimum zone (OMZ). Varves and three types of oxygen-tiered bioturbation are used to detrive an OMZ index (OMZI) that quantifies changes in the OMZ. Major fluctuations are sustained for hundreds of years and represent changes in oxygen concentration from near anoxia to more than 0.2 ml/l. The distribution of OMZI values along 400 km of the slope coincides with the present pattern of wind stress and upwelling, and past increases in the intensity of the OMZ can probably be explained by variability in the existing wind-stress regime.

QUATERNARY CLIMATIC RECORDS FROM THE PACIFIC COASTS OF NORTHWEST NORTH AMERICA NORTHEAST ASIA: EVIDENCE FROM POLLEN RECORDS FROM THE LAST 150,000 YEARS

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ABSTRACT

Quaternary sediments of lakes and mires on the northwest coast of North America contain pollen records which show the response of vegetation to Quaternary climatic change. In coastal Washington, British Columbia, and southeast Alaska after the last glacial maximum, lodgepole pine and alder invaded deglaciated ground and were followed in the Holocene by Sitka spruce and mountain hemlock communities. Regional climatic trends - temperature and precipitation estimates derived by applying regression equations relating modern pollen rain from the Pacific coast to mean July temperature and mean annual precipitation - are spatially and temporally coherent. Records from Icy Bay, Alaska; Marion Lake, British Columbia; and Hoh, Washington, show high temperatures and low precipitation in the early Holocene, culminating ~8,000 years ago. These data are consistent with intensified seasonal insolation changes and associated changes in sea surface temperatures and atmospheric circulation in the North Pacific.

Marine pollen in deep-sea cores from the northeast Pacific Ocean links the climatic history of northwestern North America to regional and global changes in the ocean and northern hemisphere ice sheets over the last 130,000 years. (Pollen deposited in deep-sea sediments provides continuous records of past vegetation and continental climates, records which are directly correlated with regional and global marine and atmospheric variations are documented in the same marine sediment samples.) Joint analyses of pollen and oxygen isotopes in deep-sea cores taken off southern Oregon show comparable fluctuations in coastal environments and global ice-volume. Intervals of minimal ice-volume, such as the last interglacial, are characterized by optimal development of temperate coastal forests, forests associated with higher temperatures and abundant precipitation.

The complexity of climatic change during the last 150,000 years is illustrated by terrestrial and marine signals from deep-sea cores taken in the northwest Pacific Ocean. Pollen and radiolarian assemblages from a core taken ~44ON show stable basically cold conditions in northeastern Japan and in the northeast Pacific from ~70,000 to ~20,000 years ago. Contrasting nonglacial environments (~10,000-4,000 years before present) are warm and humid with surface waters in the northwest Pacific characterized by warm winter and cold summer temperatures. Terrestrial and marine records from sediments in deep-sea cores taken off the Pacific coast of Japan. (RC14-99, 37ON, 148OW; and V28-304 28ON, 134OW) record frequent fluctuations in temperate vegetation during the last full glacial. From 70,000 to 128,000 years ago, major changes between warm temperate and cool temperate vegetation characterize nonglacial and glacial intervals in central and southern Japan. In central Japan, the last interglacial (128,000 to 118,000 years before present) is characterized by high precipitation and temperatures corresponding with global environmental

reconstructions of this interval. At the same time precipitation, and possibly temperatures, was low in southeastern Japan and sea surface temperatures offshore were cool. These apparently anomalous climatic signals may reflect regional circulation changes in northeast Asia during the last interglacial-northward displacement of atmospheric and marine fronts during early summer monsoons.

INTERANNUAL VARIABILITY OF THE CALIFORNIA CURRENT: A NUMERICAL MODEL

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ABSTRACT

Results of a numerical model of the eastern Pacific Ocean are presented. The main objective of this research is to investigate the large scale, low frequency dynamics of the California current system (18ON to 55ON and from 155OW to the coast). The equations used are the reduced gravity, non-linear, transport equations in spherical coordinates. The model is forced by real winds (COADS) and has resolution in space and time of 1/12 of a degree and 30 minutes. The model runs for 19 years, from January 1961 to December 1979.

Preliminary examination of our results show the general seasonal cycle (e.g., set-up of Davidson current, formation and position of southern California eddy, etc.) to be in agreement with what has been described by other authors. However, the data also suggests the need for including the effects of equatorially generated variability. In a second experiment, the model was forced through its southern boundary using the output of a similar wind-forced equatorial model.

Through cross correlation and cross spectral analysis between the model results and observed sea-level data, it was established that most of the interannual variability in sea-level height at the coast is due to disturbances of equatorial origin that propagate into the region in the form of coastally trapped Kelvin waves. For the annual frequency variability, on the other hand, it was found that both local, as well as remotely forced variability, contribute to the total variance.

THE PHYSICAL RECORD OF LAKES IN THE GREAT BASIN DURING THE LAST DEGLACIATION

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ABSTRACT

Comparison of chronologies of the last (Late Wisconsin) lake-cycle in the Lahontan and Bonneville basins indicates that: (1) lake-level rises occurred gradually in both basins; (2) the gradual rise in lake level appears to have been interrupted by a possible recessional event at ~16 ka; (3) the subsequent decline in lake level occurred rapidly, although perhaps at different times in each basin.

The lowest lake stands recorded in the Bonneville basin occurred immediately after the decline from the pluvial highstand. Following this lowstand, Lake Bonneville rose at about 10.3 ka to the Gilbert shoreline, well above the historic level of Great Salt Lake, A similar sequence of events occurred at the Ruby Marshes, and perhaps at Mono Lake, but in the Lahontan basin, lake-level data for the 12 to 10 ka period are lacking. The events are poorly dated except in the Bonneville basin, and although the stratigraphic sequences are similar across the Great Basin, the events may not have been synchronous. The range of climatic variability, as expressed by changing lake levels, appears to have been much greater between 13 to 10 ka than during the Holocene. The marsh chronologies from the Mojave Desert region of southern Nevada do not reflect the degree of variability indicated by the lake records from farther north. Instead, the marsh data indicate a progressive unidirectional trend in desiccation from 13.5 to 7.5 ka. The delay in apparent desiccation may have resulted from the lag time implicit in the noninstantaneous transport of water from areas of recharge to areas of discharge (marshes).

The last lake cycle is hypothesized to have occurred as the result of two processes: (1) forcing of one branch of the jet stream south by the presence of a large and high continental ice sheet and (2) by the initiation of lake-climate feedback processes.

Montane glaciers appear to have begun their recession prior to the last lake highstand. It is hypothesized that this was caused by a shift in seasonality, whereby: (1) precipitation generated by the westerlies caused more summer precipitation, or (2) winters became warmer.

RECORDS OF CLIMATIC VARIABILITY FORM THE TROPICAL QUELCCAYA ICE CAP, PERU AND THE DUNDE ICE CAP, CHINA WITH EMPHASIS ON THE ENSO EVENTS

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ABSTRACT

The analyses of two ice cores from the tropical Quelccaya Ice Cap, Peru, provide a record of climatic conditions over 1500 years for a region where other proxy records are nearly absent. Annual variations in visible dust layers, oxygen isotopies, microparticle concentrations, conductivity, and identification of the historical (A.D. 1600) Hyaynaputina ash permit accurate dating and time-scale verification. The fact that the Little Ice Age (about A.D. 1500 to 1900) stands out as a significant climatic event in the oxygen isotope and electrical conductivity record confirms the worldwide character of this event. The very accurate time resolution has allowed the comparison to be made of the historical El Niño events of Quinn, Neal and Antunez de Mayolo, 1986, and the ice core parameters over the last 450 years.

Results from the first glaciological investigation of the Dunde ice cap demonstrate that a long, highly temporally resolvable climatic ice core record is preserved in this ice cap. Measurements of stratigraphy, microparticle concentrations, liquid conductivity, and oxygen isotope ratios from snow pits and a 34.5 meter core suggest that the annual accumulation rate of ~200 mm (water equivalent). Borehole temperatures of -5.40C at 30 meters indicate that the ice cap is polar. Monopulse radar depth determinations yield an average thickness of 140 meters, which coupled with the smooth bedrock topography and the current accumulation rate, suggest that the Dunde ice cap should contain at least a 3000 year climatic record from this subtropical location. Based on the preliminary evidence from ice core parameters over the past century it is believed that major ENSO events are recorded on the Dunde ice cap as years of reduced accumulation as in the case of the Quelccaya record. It is believed that the Dunde ice cap cores to be recovered during the summer of 1987 in conjunction with the Quelccaya records will yield an annual to decadal record of climatic variability and perhaps teleconnections between both sides of the Pacific Ocean basin.

CLIMATIC CHANGE AND THE RELATIVE STABILITY OF DESERT PLANT COMMUNITIES

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ABSTRACT

A predominant view in plant ecology portrays succession as a slow regenerative process, especially in environments inhabited by long-lived species. According to this view, stability increases as succession progresses. Because the climax species are long-lived, changes in the undisturbed climax, such as those resulting from interannual climatic variability, should be minor and occur as random fluctuations about some long-term mean. This model of "convergent succession" is currently being evaluated for plant communities in the North American deserts. Desert plant communities are commonly ascribed remarkable stability despite their dramatic response to climatic change in recent geologic time. In the Sonoran Desert, packrat midden studies record compositional changes due to sequential immigration of plant species from the end of the Pleistocene to as recent as a few millennia. Even after their arrival, species continued to respond dramatically to climatic change--blue paloverde (Cercidium floridum) and catclaw acacia (Acacia greggii) retreated from dry, south-facing slopes to desert washes as aridity increased throughout the Holocene (Van Devender 1987).

In the Mojave Desert, Webb et al., (1987) measured shrub communities in a variety of disturbed and undisturbed sites, including debris flows of various ages, ghost towns, and an abandoned pipeline. Though the variability of species composition among disturbed sites exceeds that among undisturbed and geomorphologically stable sites, in accord with convergent succession, the time span for recovery after disturbance may be longer than past periods of climatic and geomorphic stability. Long-term demographic data are now available from a few Sonoran Desert sites. A set of plots established in 1906 and mapped at irregular intervals through 1978 at Tumamoc Hill near Tucson, Arizona, experienced no consistent, directional changes in vegetation composition, despite large fluctuations in absolute cover and density of most species in response to sequences of either exceptionally wet (e.g., 1930-1936) or exceptionally dry (e.g., 1950-1957) years (Goldberg and Turner 1986).

A related study is now being conducted at McDougal Crater (Parque Nacional dePinacate, Sonora), a 140-m deep volcanic crater inaccessible to livestock and unscathed by other human disturbances. A series of matched photographs, beginning in 1907, and detailed maps of permanent plots, dating from 1959, show that long-lived species, such as paloverde (Cercidium microphyllum), mesquite (Prosopis glandulosa var. torreyana), saguaro (Carnegiea gigantea),and creosotebush (Larrea tridentata), have undergone marked population changes since 1907. Species with relatively stable populations for the first half of this century have abruptly declined (creosotebush) or dramatically increased (mesquite) during the past two decades. Saguaros increased rapidly during the first half of the century, then maintained high populations for the past 27 years. The three to ten-fold reduction in creosotebush seems remarkable for a plant that may live to be several thousand years old. Its observed decline, and that of paloverde, is related to the prolonged drought of the 1940s through 1960s. Recent recruitment of mesquite and saguaros is thought to result from a series of summer rainfall events. Because the species assemblage is composed of two suites of species, one with recruitment responding to summer and the other to winter rainfall, population changes may result from the kinds of shifts in

seasonality envisioned for periods dominated by El Niño vs. anti-El Niño years. It is proposed that desert plant communities are no more stable than the climatic regimes that support them.

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Van Devender, T.R. 1987, Holocene vegetation and climate in the Puerto Blanco Mountains, southwestern Arizona. Quaternary Research 27, pp. 51-72.

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EVIDENCE FOR HOLOCENE CLIMATIC HISTORY OF NORTHERN COASTAL PERU

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ABSTRACT

The yperaridity of coastal Peru is a result of three predominant factors: the rain shadow effect of the Andes, the stability of the Peru-Chile current and the related coastal upwelling, and the stabillity of the South Pacific anticyclone. Episodically, perturbation of the South Pacific anticyclone allows for a reorganization of the equatorial water masses, and the Peruvian coastline becomes bathed in warm equatorial waters. These events, referred to as El Niño events, can bring major flooding to the Peruvian desert. Stratigraphy and sedimentology of flood deposits (Wells, 1986 and submitted), paleontology of coastal deposits (Wells and DeVries, in progress), and edology of the coastal and fluvial sediments (Noller, Wells and Birkeland, 1987) in the areas from Rio Casma to the Salinas de Santa (8.5OS to 10OS) have been studied to record the history of this climate regime, as a function of precipitation and sea surface temperature during the Holocene.

The late Holocene history of El Niño flooding is recorded in the overbank flood sediments, preserved in flood plain terraces. Incision, which occurs in the years between El Niño events, exposes the top 1 to 10 meters, temporally the last 6-7,000 years, of these deposits. A minimum of ten major flooding events have occurred during this time; the timing of these events is bracketed by archaeologically defined isochrons. These floods required discharges much larger than that which occurred during the 1982-1983 El Niño, as the floods of 1982-1983 did not overflow onto this terrace. The sediments of the flood plain are sedimentologically identical to the deposits of the 1982-1983 El Niño-like events are therefore suggested to have occurred at least throughout the Holocene.

The climate history for non-El Niño years is recorded by the soils developed on now-buried flood deposits and on correlative alluvial fan terraces. Buried agricultural soils on the late Holocene deposits are composed of thin organic A horizons and oxidized C horizons. Soils developed on the pre-agricultural deposits (agriculture began c. 5,000 P) are composed of oxidized C horizons exclusively. In the alluvial fan environment, stable Holocene surfaces have been exposed for 5,000 to 10,000 years. Soils on these surfaces reflect an integration of the climate over the time of surface exposure. In the coastal zone, early and late Holocene soils on alluvial fan deposits are composed of a vesicular silty A horizon, a halite and/or gypsum B horizon, and an oxidized C horizon. Any change to a wetter climate regime in the Holocene would have resulted in: 1) better development of the soils in flood plain, and more organics in the surface horizons of the pre-agricultural soils, and 2) removal of salts from the soils in the alluvial fan terraces and the deposition of clay in the B horizons of these soils. The absence of either of these phenomena argues for continuation of an arid climate throughout the Holocene.

Rollins <u>et al.</u> (1986) argument for a savannah-type climate in the early Holocene is based on the presence of early Holocene warm-water molluscan fauna, now absent from the Peruvian coastal zone. Wells and DeVries (in

progress) argue that this fauna are facies controlled; warm-water lagoonal environments, present around the time of sea-level stabilization, have since been lost as a result of coastal progradation. The early Holocene molluscan faunas (collected from in situ lagoonal deposits and from human midden deposits) are composed of warm lagoonal and estuarine species living concurrently with cold water rocky headland and beach species. There is, therefore, no overwhelming evidence for the presence of warm coastal water, at least as far north as 8OS, during the early Holocene.

Continued episodic flood events, stability of soil forming processes and a continuous cold water open marine fauna together suggest that precipitation has been restricted to El Niño events, and that near shore sea surface temperature has remained constant throughout the Holocene. These three lines of evidence suggest that no major climatic changes have affected coastal Peru during the Holocene.

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SOUTHERN ARIZONA FLOODS DURING EL NIÑO YEARS:
FLOODPLAIN MANAGEMENT IMPLICATIONS

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ABSTRACT

Probabilistic methods of flood frequency analysis, such as the Log Pearson Type III distribution (LP III) recommended by the U.S. Water Resources Council, are the primary source of regulatory and design flood estimates nationwide. These methods generally assume that the hydrological characteristics of a stream have not changed over the period of flow measurements (i.e., that the mean and moments of the distribution are stationary). The need to verify this assumption cannot be taken lightly. The "100-year flood" (Q100) is now a household, if not a commonly misused, concept. In thinking that he has 100 years to worry about it, the ordinary citizen may be no more mistaken than the floodplain engineer who assumes stationarity a priori.

In southern Arizona, there has been increasing concern about nonstationarity in annual flood series stemming from climatic trends (big floods tend to cluster during wet periods); mixed populations of events (e.g., floods produced by convective vs. frontal storms); and watershed history (e.g., effects of urbanization or significant changes in channel topography). The potential for nonstationarity is probably greatest in this part of the country because interannual climatic variability is high, streamflow is characterized by large ratios of maximum to mean discharge, alluvial channels are relatively unstable, and most urban watersheds have experienced tenfold growth in population since World War II. Because of catastrophic flooding in recent years, the climatic setting for large floods in southern Arizona has stirred considerable interest. Are watershed changes due to progressive channelization and intensified land use now translating moderate rainfall into higher flood peaks, or has there been a recent shift in climate featuring unusually heavy rainfall?

There is a striking correspondence between intense El Niño events and the roster of regionally significant floods in southern Arizona and the Southwest as a whole (e.g., 1890-91, 1940-41, 1982-83). Douglas and Englehart (1983) found a moderate correlation between El Niño in the tropical Pacific during the previous summer and heavy precipitation in the Southwest during the fall and following winter and spring. Although annual flood peaks in the region occur most frequently in July and August as a consequence of monsoonal activity, the largest peaks typically result from frontal storms and tropical storm-cutoff lows in winter and fall. Over half of the Pacific tropical storms that tracked inland between 1900 and 1983 produced significant flooding somewhere in the Southwest (Smith 1986). Peaks in fall and winter were most common during periods of frequent El Niño episodes (e.g., pre-1930 and post-1960). They were least common from 1930-1960, a period when El Niños were infrequent, annual flood peaks occurred predominantly in July and August, and low flow conditions were prevalent. Hence, design and regulatory flood estimates are probably too low if heavily influenced by the period 1930-1960. Alternatively, Q100 could be calculated for runoff produced by different storm types (Hirschboeck 1985) or for El Niño vs. anti-El Niño years.

The Santa Cruz River, an ephemeral stream that flows north through Tucson and empties into the Gila River on the outskirts of Phoenix, provides

an excellent opportunity to evaluate some of these concerns. Tucson boasts a 116-yr climatic record, 68 years of streamflow measurements, and over a century of observations about channel history. The city has experienced phenomenal growth, from a sleepy town of just a few thousand at the turn-of-the-century to a modern metropolis of half a million people. The lower valley of the Santa Cruz, downstream from Tucson, is a broad alluvial plain, where sediment moved by major floods is stored for centuries if not millennia. Until recently, little water or sediment originating in the upper or middle reaches of the Santa Cruz actually reached the Gila. Prior to 1890, the river ran mostly on the surface of the valley. Large floods in summer of 1890 scoured a channel with vertical walls tens of meters below the valley surface, paralleling similar developments in other alluvial valleys throughout the Southwest. This arroyo has continued to evolve through headcut migration and channel widening during major floods, producing significant changes in river form throughout the period of streamflow measurement (1915- 1984) (Betancourt and Turner, in press).

As is commonly the case, public awareness of the river's instability was aroused by an unusually large flood in October 1983 (Tropical Storm Octave) (Saarinen et al., 1983). This event (1490 cms) more than doubled the previously estimated Q100 and resulted in damages of up to half a billion dollars. Attempts to update Q100 since the flood have yielded a wide range of values from 740 to 2800 cms, depending on the technique and length of record. Such a large discrepancy in Q100 has confused the general public and fostered skepticism among those entrusted with floodplain regulation and management. The principal concern is with an apparent increase in flood peaks during the last two decades due to improved channel conveyance and reduced channel storage, an increase in heavy rainfall from dissipating tropical storms and hurricanes in the eastern Pacific Ocean related to El Niño, or a combination of both.

As with other southern Arizona streams, the Santa Cruz flood series shows a lack of uniformity in the seasonality of flood peaks (Fig. 1). In the periods 1915-1930 and 1960-1984, almost half of the annual flood peaks occurred in early fall (September-October) or winter (November-February). In the intervening period of 1931-1959, 93% of the annual peaks occurred in July or August. The peaks prior to 1930 may have been attenuated by channel storage in an unincised floodplain upstream of Tucson. In other words, the peak in 1915 might have been much higher if routed through the modern channel configuration. On streams such as the San Francisco River upstream of Clifton, where shallow bedrock limits changes in channel topography, annual peaks prior to 1930 were noticeably larger than those between 1930-1960. Seven of the eight largest peaks in the Santa Cruz flood series were produced by fall or winter rainfall and five of these occurred after 1960.

Whether related to climatic or watershed changes, the results of flood-frequency analysis change with the period of measurement. Q100, using a Log Pearson Type III distribution, is doubled if the flood series is restricted from 1915-1984 to 1961-1984 (Fig. 2). Another approach is to examine subpopulations of flood peaks by storm type, test each annual series by storm type for trend, and compute recurrence intervals for each storm type. Hirschboeck's (1985) analysis, using the partial duration series from 1950-1980, suggests that Q100 for winter frontal storms and fall tropical storm-cutoff lows is double that from the summer monsoonal storms that are the most common source of flood peaks (Fig. 3).

The Santa Cruz Valley's economic future may be deeply affected if large floods persist in coming decades. The 1983 event produced incipient erosion in the lower Santa Cruz valley, where the stream gradient is steepened downstream of the zone of maximum aggradation. Should this reach become channelized, significant volumes of water and sediment may leave the system for the first time in centuries, if not millennia, silting up farmland and reservoirs along the Gila River.

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Fig. 1

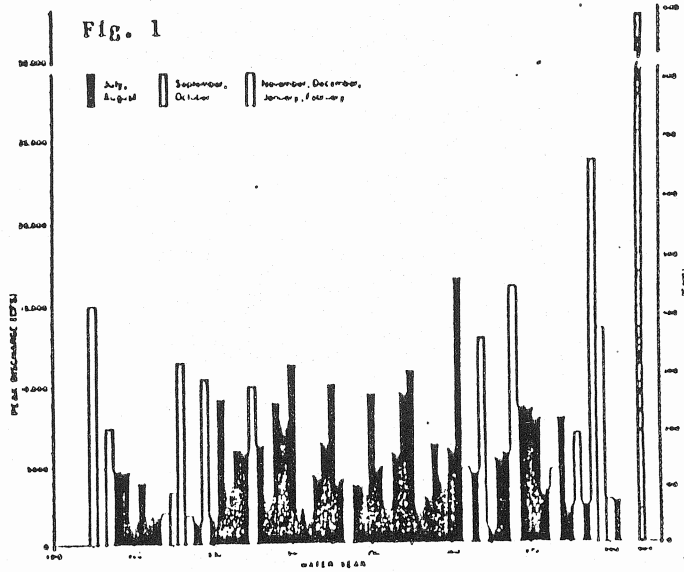

Fig. 2

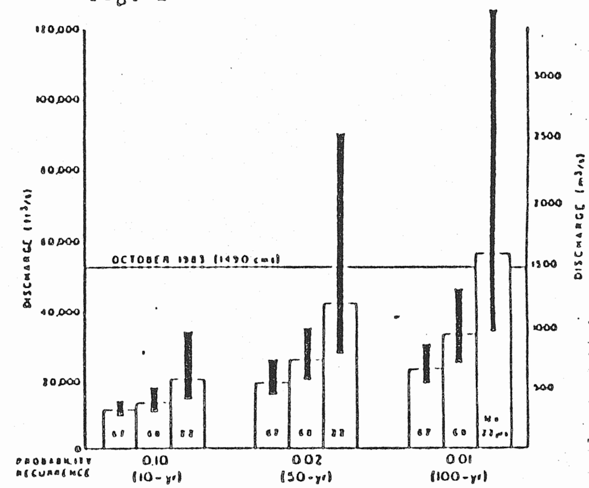

Fig. 3

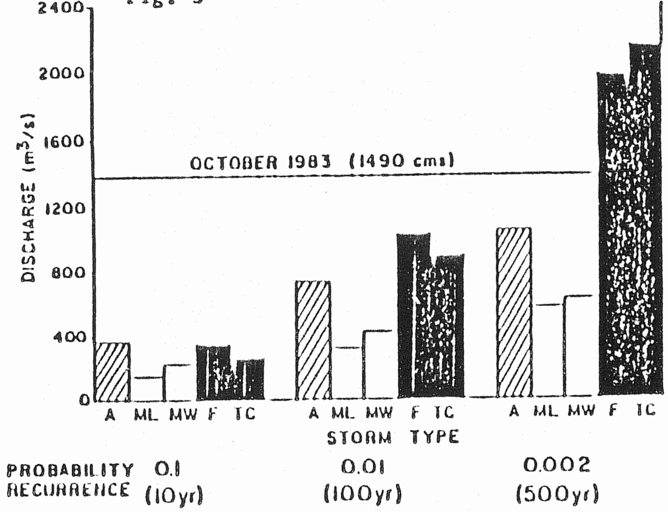

Figure 1. Annual flood peak series for the Santa Cruz River, Tucson, 1915-1984..

Figure 2. Estimated discharge (LP III) for 10-yr, 50-yr, and 100-yr recurrence intervals, based on annual flood peaks from 1915-1981 (67 yrs), 1915-1984 (68 yrs), and 1961-1984 (22 yrs), Santa Cruz River, Tucson. Solid bars are the confidence limits.

Figure 3. Flood estimates (LP III) for 10-yr, 100-yr, and 500-yr recurrence intervals for different storm types in the partial duration series from 1950-1980, Santa Cruz River, Tucson. A= annual, ML= monsoonal local, MW= monsoonal widespread, F= frontal, TC= tropical storms and cutoff lows (adapted from Table 9, Hirschboeck 1985).

LONG TERM SARDINE FLUCTUATIONS ALONG THE COAST OF NORTH AMERICA

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Centro de Investigaciones Biologicas de Baja California
Richard A. Schwartzlose
Scripps Institution of Oceanography

ABSTRACT

Causes of the California sardine fluctuations have been hypothesized by many authors. We are presenting a new interpretation of the catch data as related to global climatic and oceanographic long-term trends.

We hypothesize that the size of the population depends mostly on the extension of the habitable area, and that this temperate area is enlarged or reduced according to global climatic and oceanographic trends; reducing towards its near-tropical limits with cooling trends and enlarging towards the subarctic zone with warming trends.

We are using global data series to construct a general averaged climatic-oceanographic trend from 1930 to 1985, noting its outstanding features and comparing them to sardine catch data along the North American coast.

LARGE SCALE ATMOSPHERIC CIRCULATION AND STREAMFLOW IN WESTERN NORTH AMERICA

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and
Dave Peterson
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ABSTRACT

This is a report on a preliminary study of the link between large scale atmospheric circulation over the North Pacific in winter and streamflow in western North America. Streamflow, while not a traditional meteorological variable, is useful because it integrates over a relatively long period and large area of "noisey" precipitation data. In the western United States, streamflow is to a large extent driven by winter season precipitation from active North Pacific storms. Thus, a better understanding of the linkage between atmospheric circulation, precipitation, and streamflow in the West is of major importance to managing the water supply. Our interest in this link was inspired when one of us (DP) noticed considerable differences in streamflow chemistry for very wet years vs. very dry years, and we began to compare streamflow patterns with winter circulation types.

Monthly streamflow data beginning as early as the late 1800s over a region from Alaska to Arizona, including stations as far east as Idaho, Utah and Nevada, and with two stations in the Hawaiian Islands. In all, we composited monthly stream gauge records from about ten areas within the western region. Gridded atmospheric sea level pressure (SLP) monthly data is available from 1899 through the present.

Results so far suggest that both the temporal and spatial characteristics of stream flow in several basins are different in the period during and subsequent to winters with strong lows over the North Pacific than those with weak lows there (Fig. 1). The "strong" low cases include several historical El Niños that have occurred since the beginning of the century; of 25 winters that fell into the "strong" winter category, 13 were El Niños. For the selected basins that were examined, both the temporal persistence and the spatial cross-correlation of monthly streamflow appear to be increased during after strong lows vs. weak lows, implying that streamflow anomalies tend to last longer and be larger in spatial extent for the strong low case (Fig. 2). Further work is aimed at better defining and explaining these relationships. In addition to increasing our network of streamflow stations, we intend to examine the behavior of the atmospheric circulation and the large scale precipitation associated with these subsets.

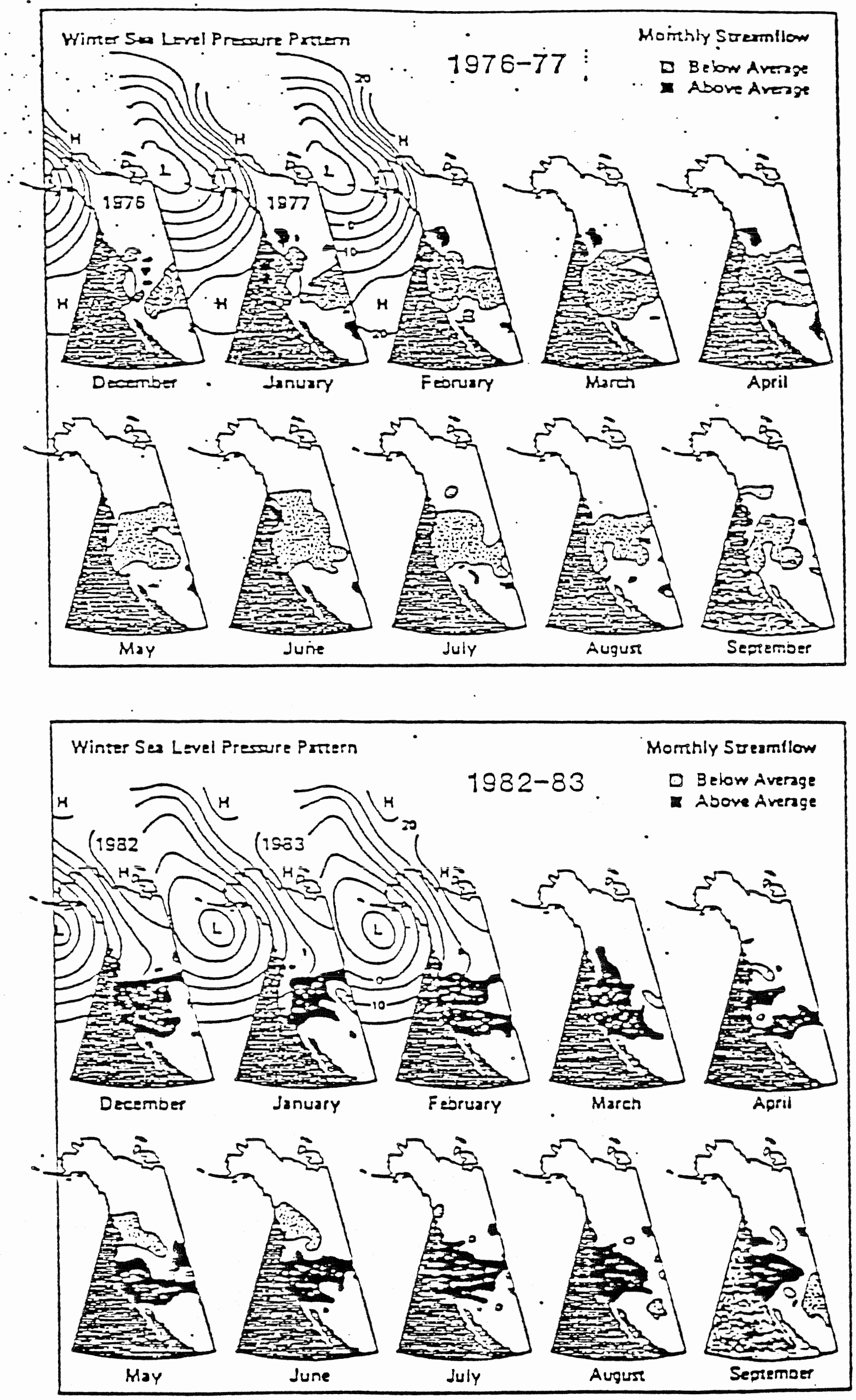

Fig. 1 Western North American monthly streamflow anomalies during and following the winters of 1976-77 and 1982-83. Anomalies are given in three cases, as presented in *EOS* by USGS. North Pacific winter sea level pressure is contoured on first few months. Note the exceptionally strong persistence in this case.

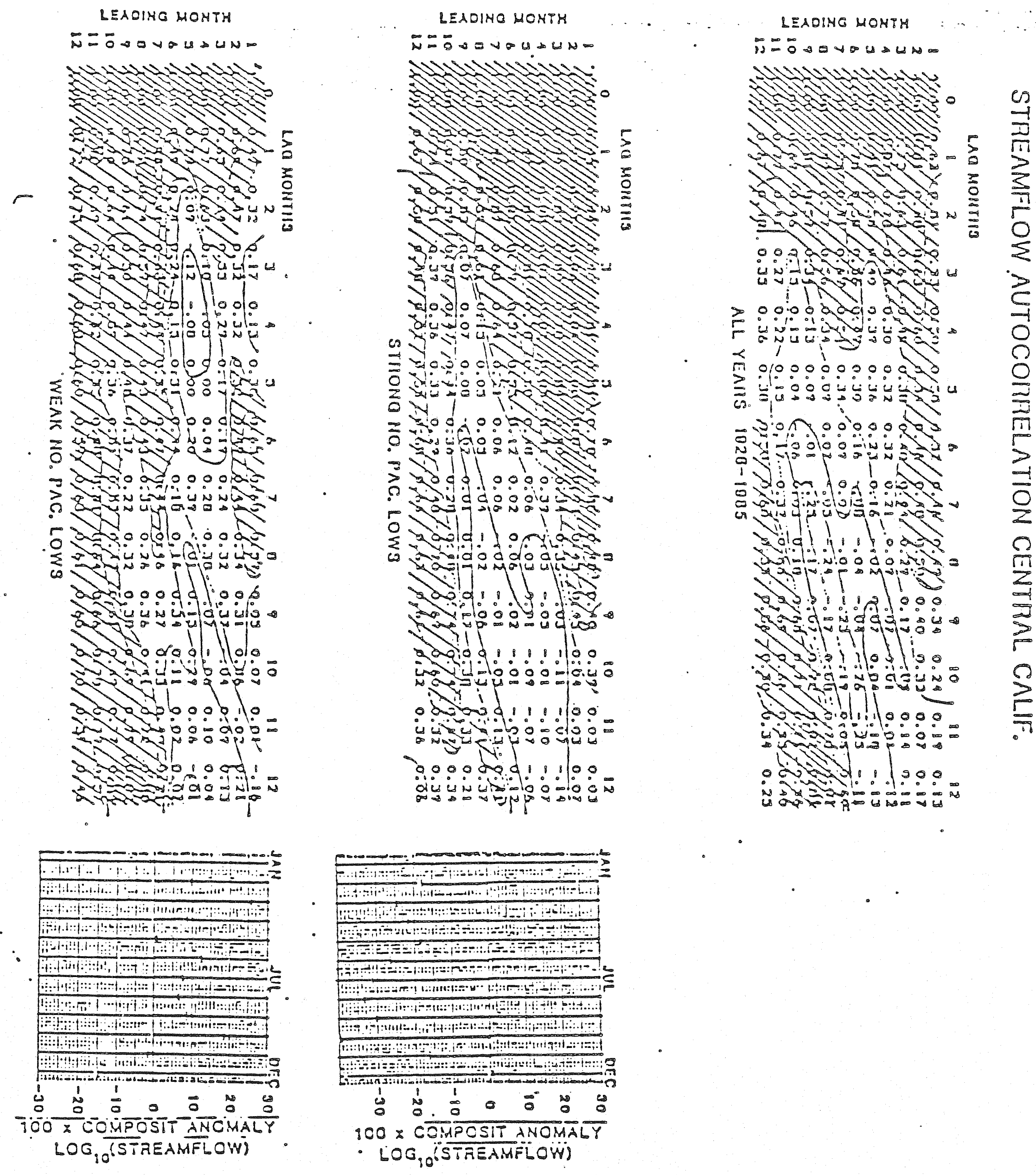

Fig. 2 Statistics from composite anomaly streamflow record of Central California streams (1926-1985), which are transformed by: $\log_{10}$ (streamflow), subtracting monthly long-term means, and standardized by the resulting standard deviation. Streams chosen were Kings River, Smith River, Merced River, Sacramento River, and Cosumnes River. Anomalies from individual streams are weighted by that stream's mean annual runoff to form composite. LHS graphs show autocorrelation, stratified by initial month, out to 12-months lag: for all years (above); for 21 strong North Pacific Low winters (middle); and for 16 weak North Pacific Low winters (below). RHS shows composite monthly anomaly for the 21 strong low years and 16 weak low years. Note that years are taken such that winter of the weak or strong North Pacific low is at the beginning of the given year considered in these statistics.

POSSIBLE CHANGES IN CALIFORNIA SNOWMELT RUNOFF PATTERNS

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ABSTRACT

The estimated natural runoff of the Sacramento Basin was examined for trends during the past 80 years of record. Since 1950 the snowmelt portion (April through July) of the total water year runoff has been decreasing. A similar trend, although not as large, was noted in the higher elevation Kings and San Joaquin River watersheds. These changes may be an indication of climatic change.

Discussion

The Department of Water Resources, in its Snow Surveys Programs, has computed the unimpaired or natural runoff for major Sierra Nevada-Cascade rivers as far back as there are decent records. Unimpaired runoff represents the runoff from a basin which would have occurred had not man altered the flow by upstream diversions, storage, or by export or import of water to or from other watersheds.

The Sacramento Four Basin Index is widely used as a measure of natural water supply available in that basin. It is computed by adding the flows of the four major rivers:

Sacramento River above Bend Bridge, near Red Bluff
Feather River at Oroville Reservoir
Yuba River at Smartville
American River at Fair Oaks (Folsom Reservoir)

The average runoff during the 1906 - 1986 period of record was about 18.3 million acre-feet (MAF). This represents over 80 percent of the total basin runoff of around 22 MF and almost all of the snowmelt. Forecasts of snowmelt (April through July runoff) have been made for over 50 years by the Snow Surveys Program staff.

Results of the trend analysis are presented in a series of four charts. The first shows the traces for water year (WY) and April through July (AJ) runoff in millions of acre feet. The Two lines are a simple regression linear best fit. There appears to be a slight upward trend in total water year runoff (primarily due to some wet years the last decade and many drought years in the 1920 and 1930 decades) but confidence in the trend is low. There also appears to be a slight decreasing trend in the April through July volumes.

In the second chart the yearly April - July amounts were expressed as a percentage of water year totals. Note that the vertical scale is expanded and does not start at zero. A rather pronounced decreasing trend shows up after 1950. The slope of the best fit line is about -.14 percent per year.

The third chart is similar, except that a four year moving average of the yearly percents was used to smooth out some of the variability. Again the major downtrend begins soon after 1950.

The fourth chart shows the cumulative departure of percentages from the 81 year averages for April through July runoff (open squares) and the water year runoff. The drought decades of the 1920s and 1930s are quite evident from the steepness of the falling line on the water year trace (black squares). However, the April-July percentage, compared to the 81 year average, shows a gradual rise to the early 1950s and then a fall which seems to be increasing after 1970. This corroborates the two preceding chart trends.

The Sacramento Basin is not predominately snowmelt. During the period of record, about 39 percent of the annual runoff occurred during the four months of April through July. Median elevation of the Four Basin drainage area is about 4,000 feet. (See the area-elevation table.)

The southern Sierra are much higher with a predominately snowmelt runoff pattern. For the combined Kings and San Joaquin Rivers (at Pine Flat and Millerton Reservoirs), April through July runoff is about 72 percent of the annual total. Median elevation is about 8,000 feet.

The second set of charts presents the same kind of information as before for the combined Kings and San Joaquin River runoff. Results are similar to those of the Sacramento Basin but not as pronounced. The slope of the best fit lines on the second chart is about -.09 percent per year compared to -.14 on the corresponding Sacramento Basin chart. However, the percentage of basin area in the snow line zone is less on these southern rivers. So, if the cause is higher snowlines during winter storms, one would expect a smaller effect on the Kings and San Joaquin Rivers. Snowlines on April 1 probable average near 6,000 feet in the southern Sierra compared to around 4,500 feet in the northern Sierra. A 1,000 feet elevation band centered on these levels accounts for 9 percent of the total area on the Kings and San Joaquin Rivers and around 20 percent of the Sacramento Basin, including sizable portions of the drier Pit River drainage.

The changes in runoff are the kind of effects which would be expected with climate warning. With warming, a greater share of the season precipitation would fall as rain and show up as increased winter runoff with reduced amounts as late season snowmelt. Is this an indication of the predicted worldwide warming induced by CO_2 and pollutant increases in the atmosphere? Or is it one of those long term periodic shifts which seem to occur in the record from time to time which can't be related to world trends? North Pacific sea surface and California rural temperatures have not shown noticeable warming during the last three decades according to observers. However, this rather pronounced reduction in snowmelt runoff percentages certainly deserves more study by climatologists and other scientists interested in Pacific Coast climate trends.

Approximate Area Elevation Data

	Sacramento Basin Four Rivers		Kings and San Joaquin Rivers	
Total Area, $miles^2$	15,500		3,180	
Elevation Band	Percent	Cum. Percent	Percent	Cum. Percent
0 - 1,000 feet	4.9	4.9	0.5	0.5
1,000 - 2,000	12.2	17.1	3.5	4.0
2,000 - 3,000	13.6	30.7	4.0	8.0
3,000 - 4,000	19.9	50.6	5.0	13.0
4,000 - 5,000	19.5	70.1	7.5	20.5
5,000 - 6,000	15.8	85.9	6.5	27.0
6,000 - 7,000	9.7	95.6	11.0	38.0
7,000 - 8,000	3.2	98.8	12.5	50.5
8,000 - 9,000	1.2	100.0	13.0	63.5
9,000 - 10,000	--	--	14.0	77.5
10,000 - 11,000			10.5	88.0
11,000 - 12,000			8.5	96.5
12,000 - 13,000			2.5	99.0
13,000 - 14,000			1.0	100.0

M. Roos
April, 1987

Chart 1

Actual and Trend of AJ and WY Runoff for SACRAMENTO FOUR BASIN INDEX

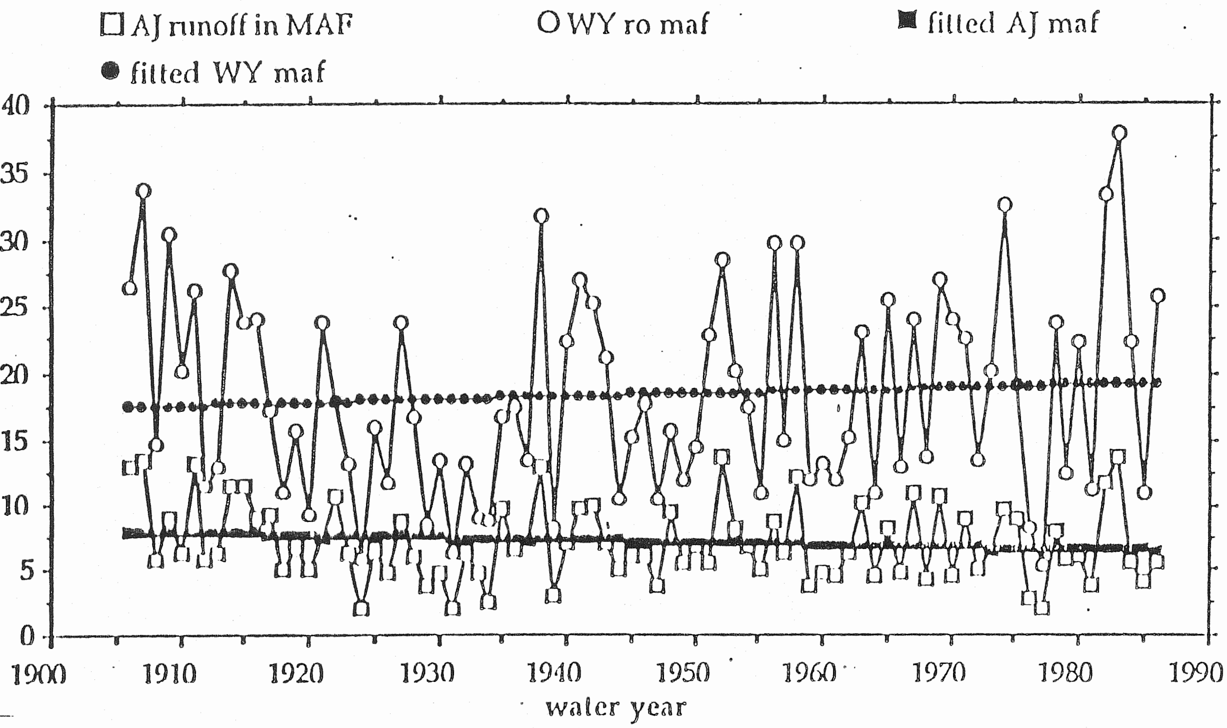


Chart 2

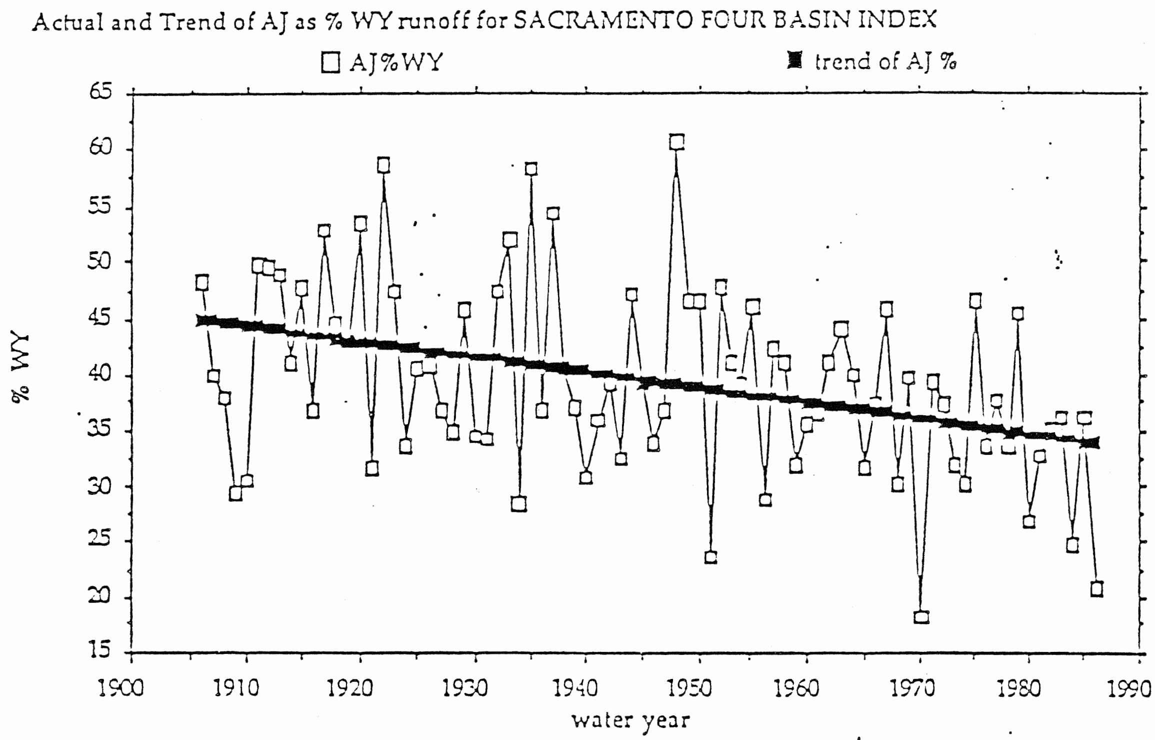
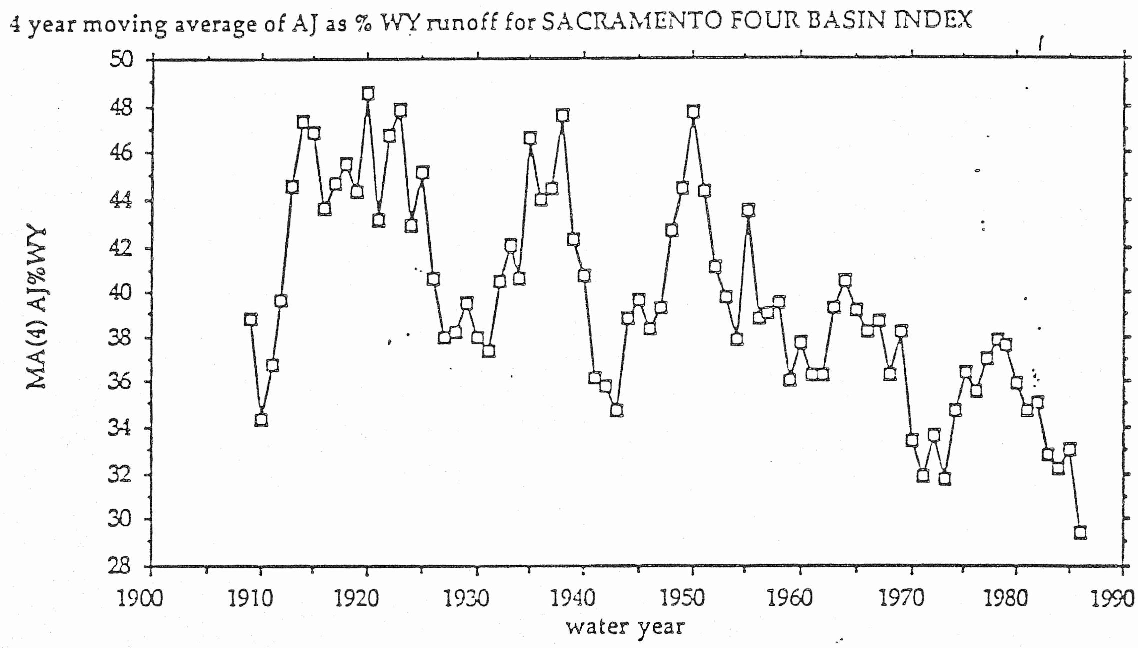

Actual and Trend of AJ as % WY runoff for SACRAMENTO FOUR BASIN INDEX
AJ%WY
trend of AJ %
% WY
65
60
55
50
45
40
35
30
25
20
15
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
water year

Chart 3



4 year moving average of AJ as % WY runoff for SACRAMENTO FOUR BASIN INDEX
MA(4) AJ%WY
water year
50
48
46
44
42
40
38
36
34
32
30
28
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990

Chart 4

Cumulative Departure from average % for SACRAMENTO FOUR BASIN INDEX

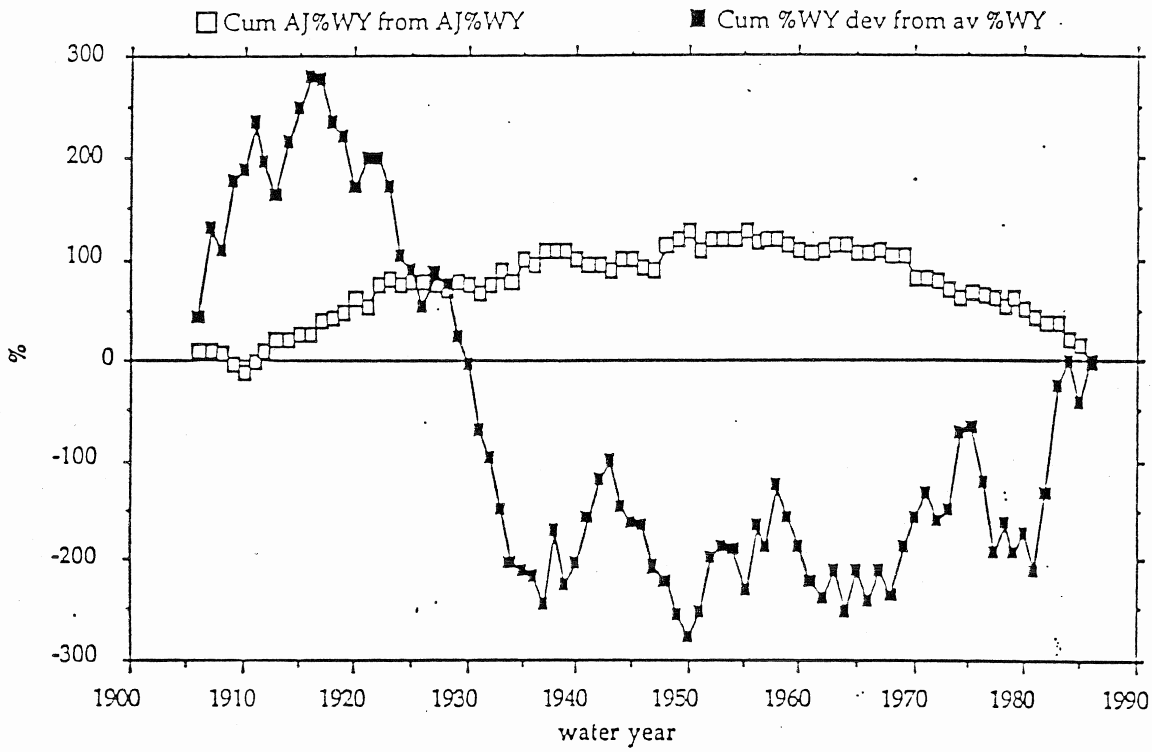


Chart 5

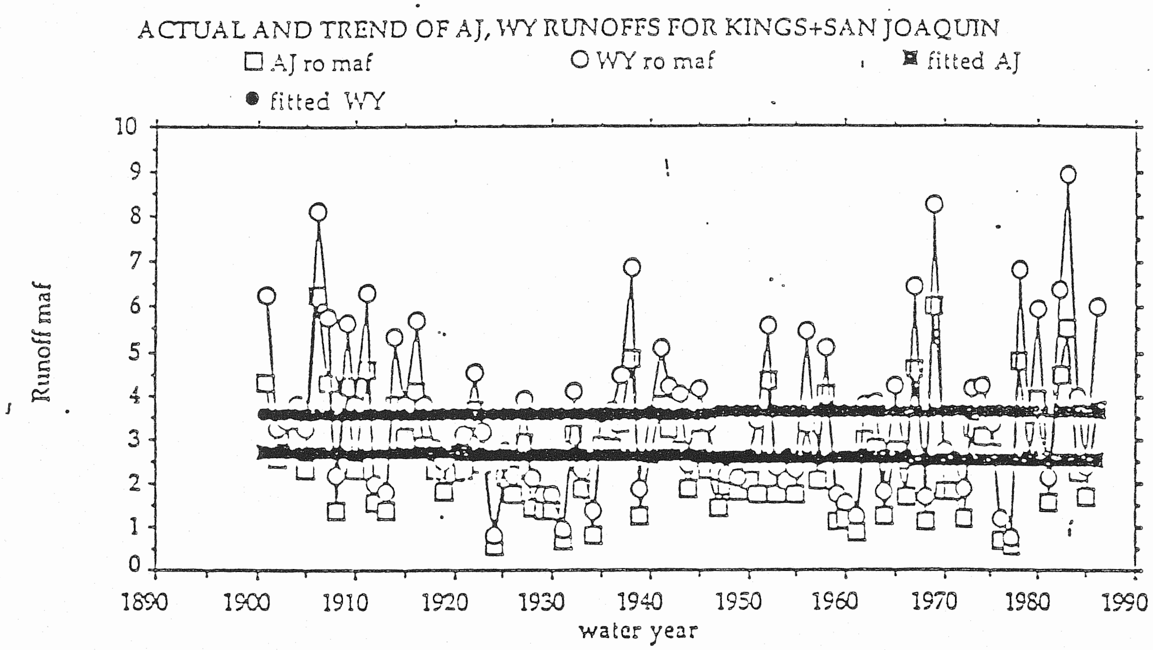
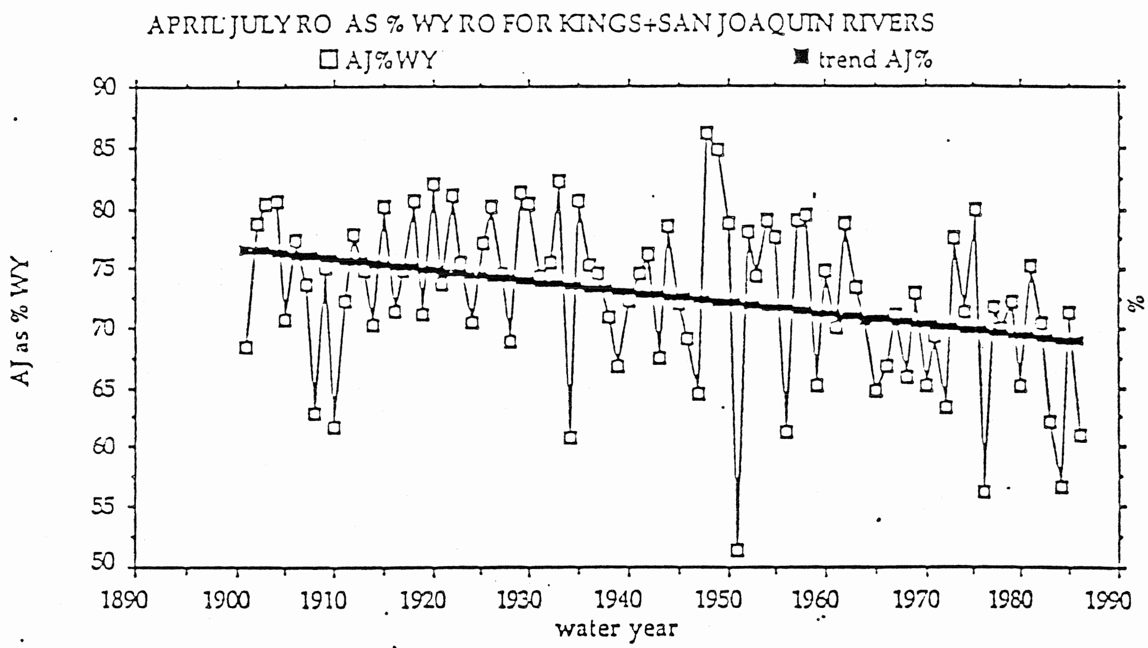

ACTUAL AND TREND OF AJ, WY RUNOFFS FOR KINGS+SAN JOAQUIN
AJ ro maf
WY ro maf
fitted AJ
fitted WY
Runoff maf
0
1
2
3
4
5
6
7
8
9
10
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
water year

Chart (



APRIL-JULY RO AS % WY RO FOR KINGS+SAN JOAQUIN RIVERS
AJ%WY
trend AJ%
AJ as % WY
%
90
85
80
75
70
65
60
55
50
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
water year

Chart 7

4 year Moving Average of AJ as % WY runoff for KINGS+SAN JOAQUIN RIVERS

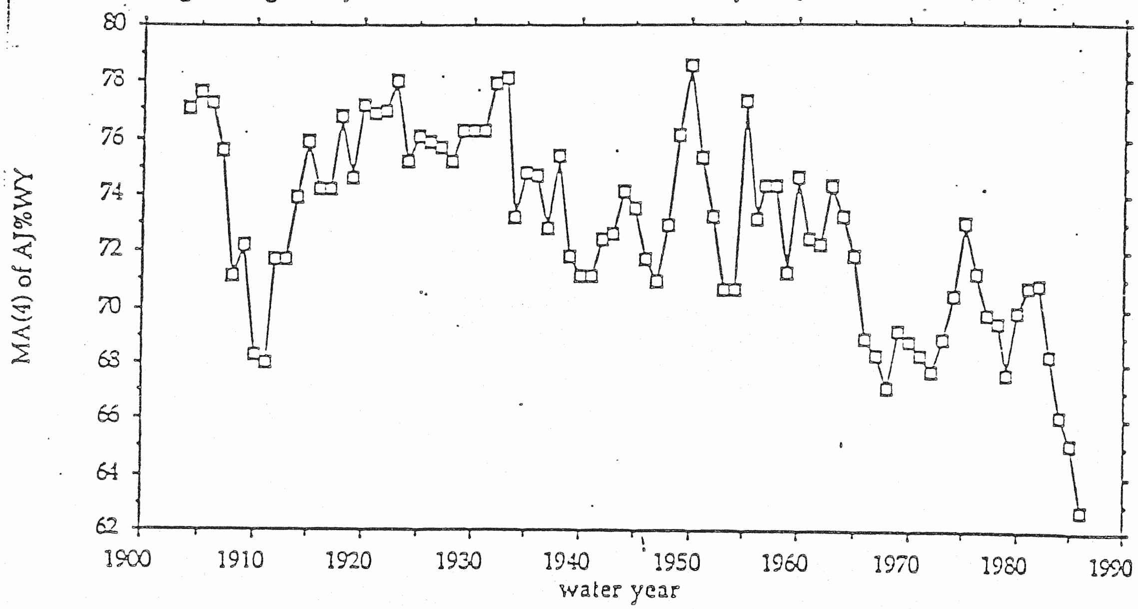
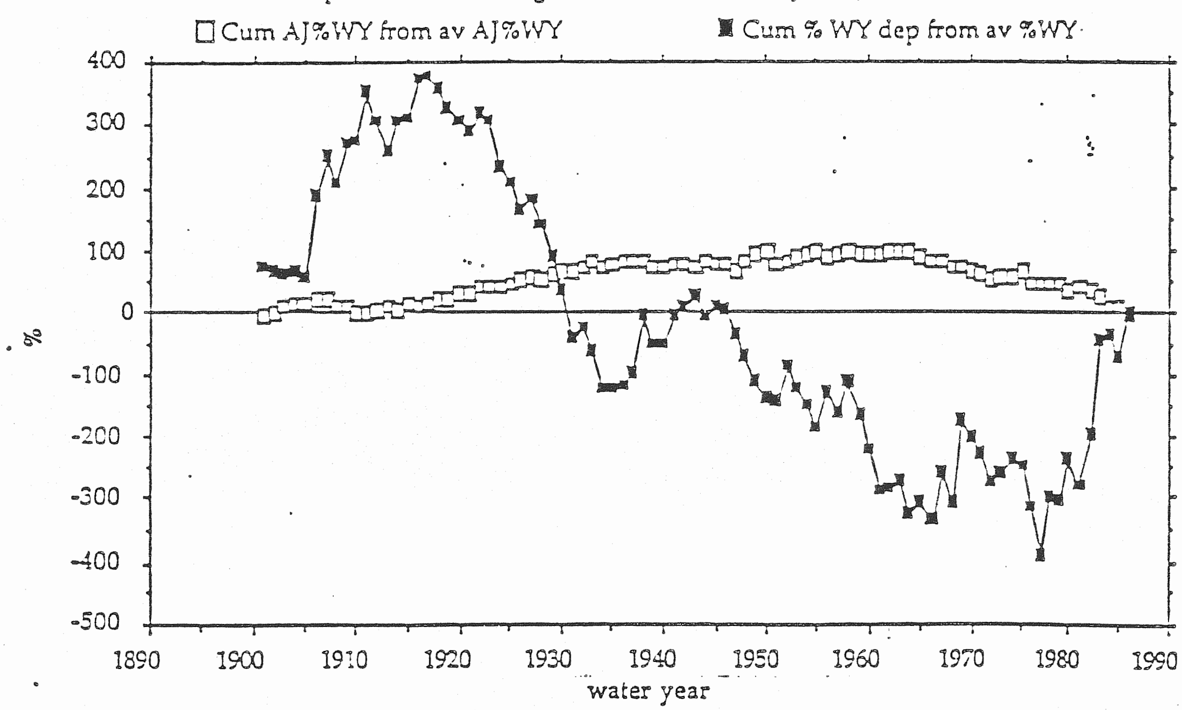


Chart 8

Cumulative Departure from average % for KINGS+SAN JOAQUIN



LONG-TERM VARIABILITY IN UNITED STATES STREAMFLOW ANOMALIES

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ABSTRACT

Analysis of long-term streamflow records in the 48 conterminous United States shows a pattern of wet and dry years with a cycle about 25 years long. The data are streamflow records at 211 stations assembled by Langbein and Slack (1982) covering the period 1911-1979. The streams are for the most part without regulation or diversion. The apparent cycle of wet and dry years is evident in each of three regions (West of the Rocky Mountains, East of the Mississippi River, and the remaining Center) of the country. The peaks and troughs of the cycles in the West precede those in the Center which precede those in the East - each by about two years.

References

Langbein, W.B. and Slack, J.R., 1982, Yearly variations in runoff and frequency of dry years for the conterminous United States, 1911-1979: U.S. Geological Survey Open-File Report 82-751, 85 p.

EVIDENCE OF CLIMATE VARIABILITY IN MARINE SEDIMENTS

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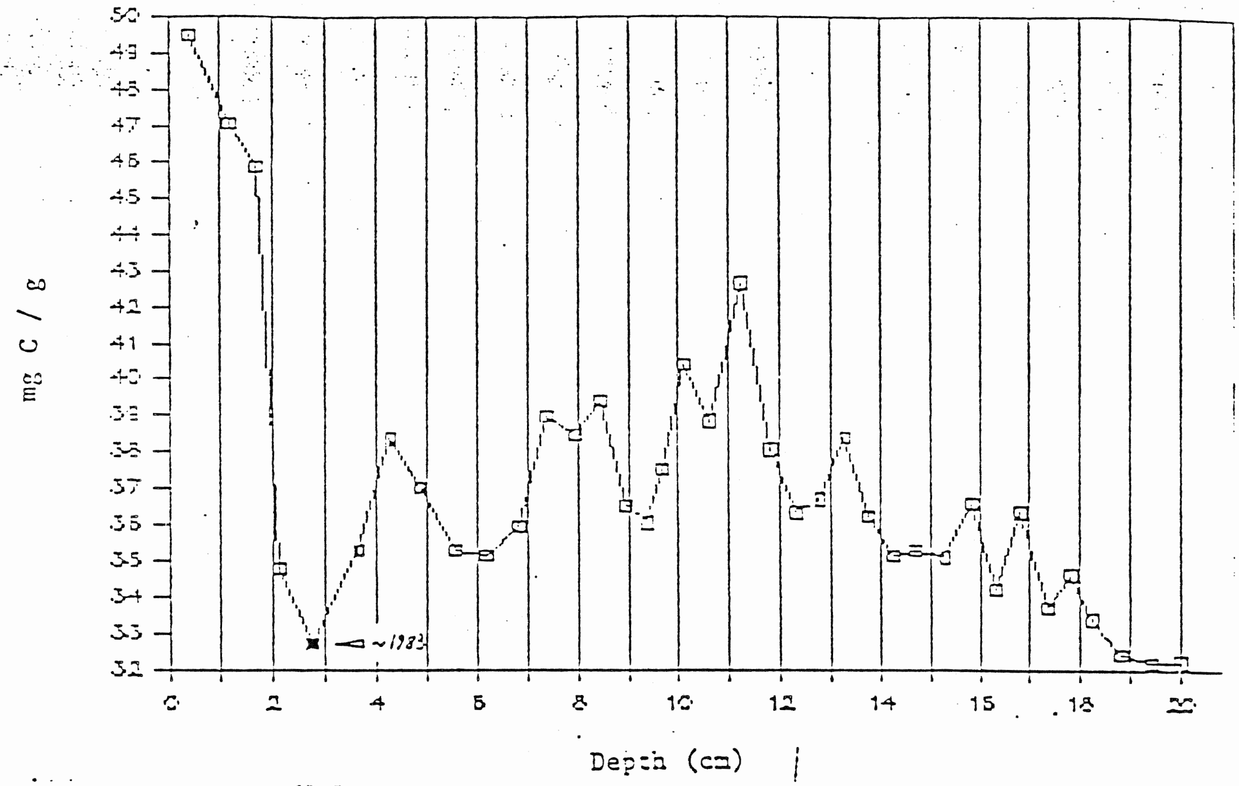
ABSTRACT

Sediment cores from the center of the Santa Barbara Basin were dissected into 2 to 10 mm intervals following coloration and sedimentological texture patterns, down to 60 cm depth. The sediment increments thus isolated from the varved, generally non-bioturbated cores represent time intervals of a few months to a year. We determined pore water concentrations and, for selected intervals, organic carbon and nitrogen concentrations of total organic matter and of isolates thereof, i.e., extractable lipids, humic acides and protokerogen. We also determined the carbon, nitrogen and hydrogen stable isotope ratios of selected organic matter isolates. This report only includes carbon stable isotopes ratios.

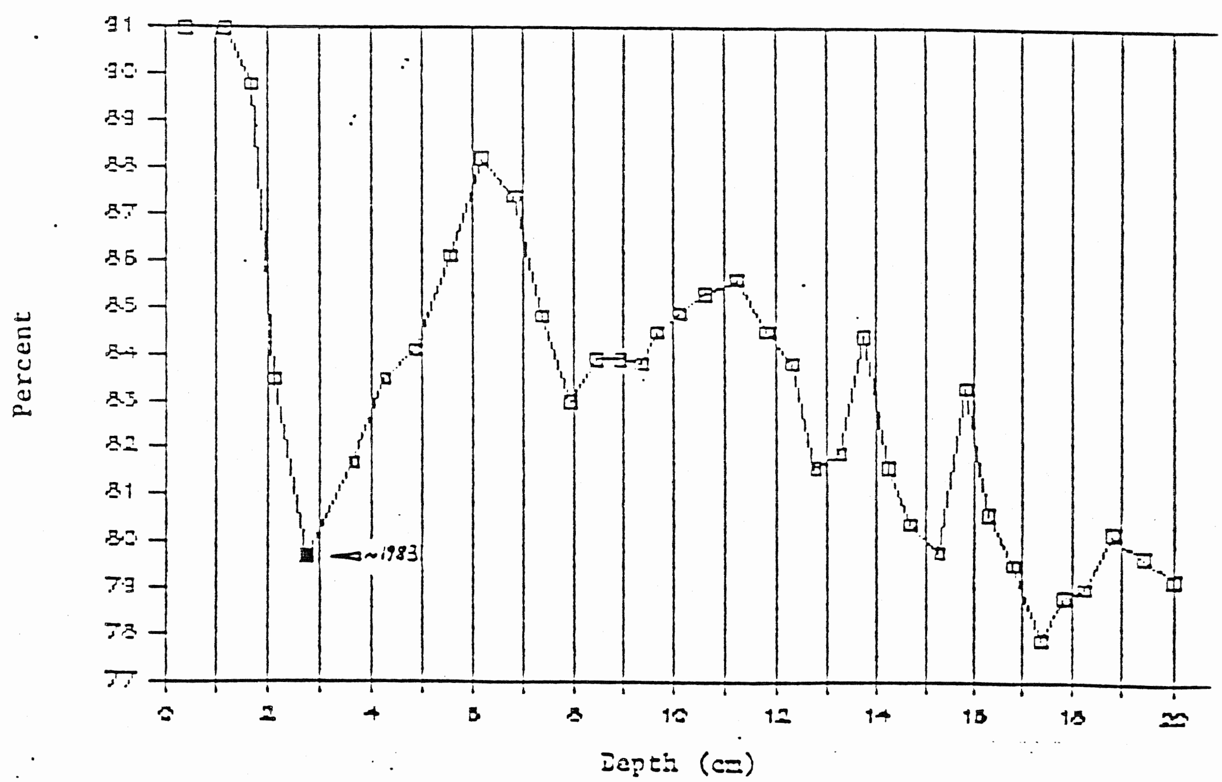
The "1983 El Niño" coincides with an unambiguous extreme geochemical signal in terms of low concentrations of pore water, total organic carbon, total nitrogen, organic isolates, and the stable carbon isotopes *13*C relative to *12*C in total organic carbon. It is as yet unclear if, and to which extent, the observed effects are the results of a suggested turbidite deposit at the same depth. The "1983 El Niño" with its higher bottom water oxygenation appears to have caused early diagenetic and/or biogenic changes a few centimeters downcore (e.g., in the depth interval 3 to 4 or ca. 5 cm) lowering the concentrations of abovenamed parameters. The affected layers had been deposited shortly before the El Niño and were then close to the surface, within reach of shallow bioturbation. The ending of the El Niño in 1984 quickly resulted in a sharp reversal of all geochemical trends.

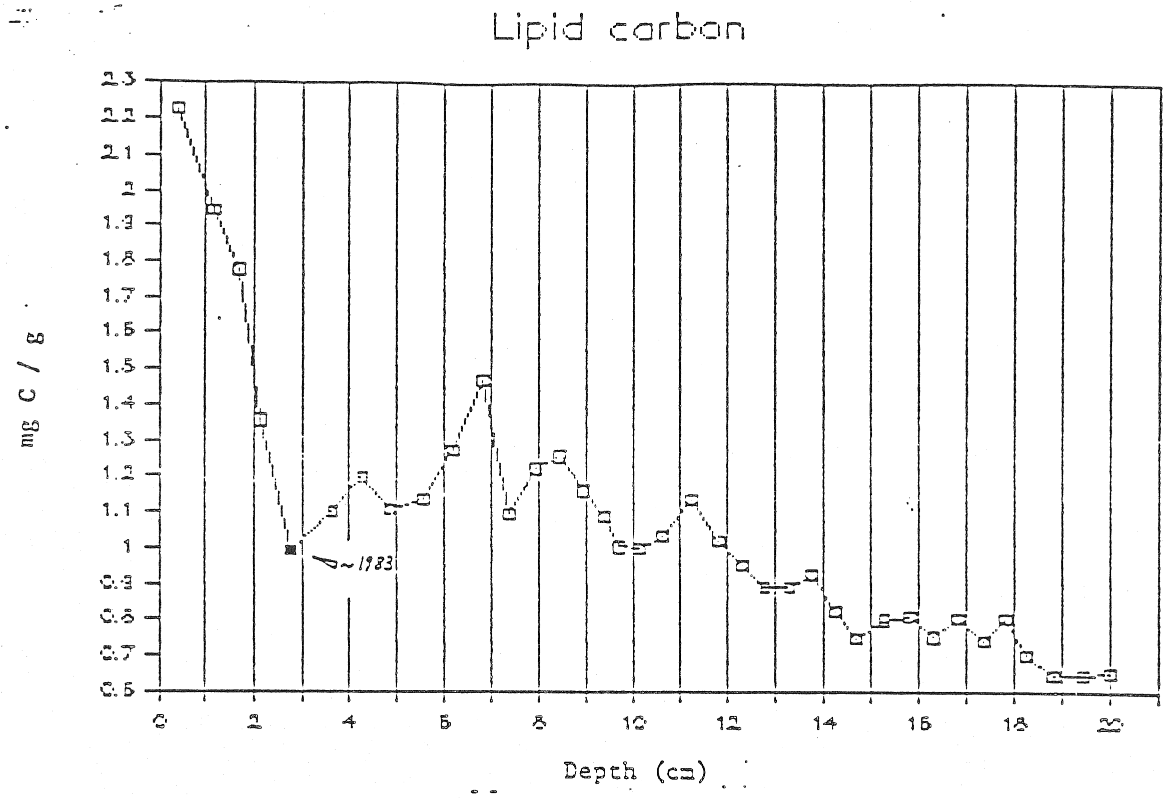
We are currently extending our geochemical approaches downcore to compare different El Niño events and to evaluate our methods for El Niño detection in prehistoric sediments.

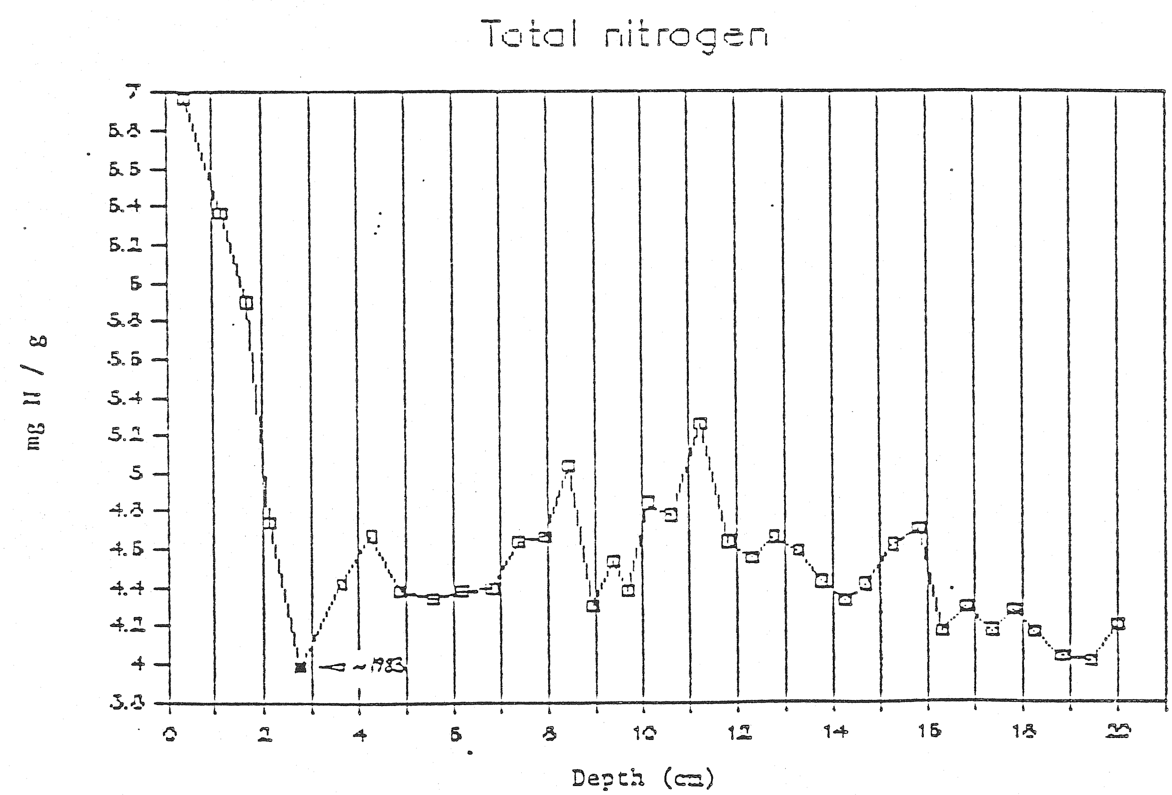
Total organic carbon

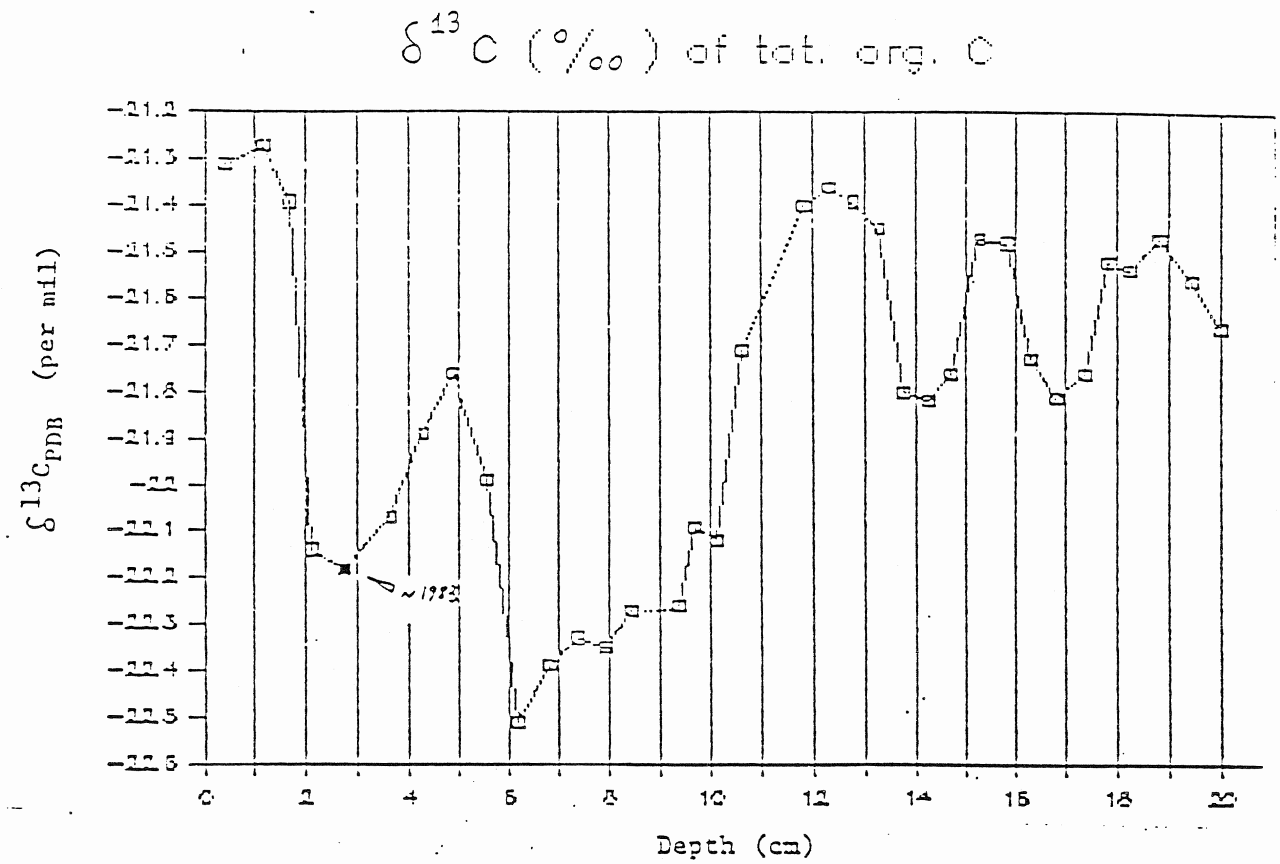


Percent water




Lipid carbon
mg C / g
Depth (cm)
~1983


Total nitrogen
mg N / g
Depth (cm)
~1983



$\delta^{13}C$ (°/oo) of tot. org. C
$\delta^{13}C_{PDB}$ (per mil)
Depth (cm)
~1985

DIFFERENT KINDS OF CALIFORNIA EL NIÑOS,
FROM RECENT AND FOSSIL RECORDS OF THE SOUTHERN CALIFORNIA SEA

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ABSTRACT

At least two different manifestations of California El Niños are detectable in both the recent and fossil record. The 1964 El Niño was much weaker resulting in a portion of the California Current moving over the Southern California Continental Borderland that was separated from the Southern California Countercurrent (very strong and carrying warm El Niño water north) by a divergence. This divergence was "filled" by northern intermediate waters moving south. These situations resulted in a radiolarian fauna containing warm radiolarians, and equal numbers of California Current and intermediate water radiolarians being preserved in the fossil (sedimentary) record of the anoxic Santa Barbara Basin. The 1983 California El Niño was much stronger resulting in subsurface invasion of California Current water onto the Southern California Continental Borderland, that was capped by warm (El Niño water) coming from the south and west. The radiolarian signature of this strong El Niño differs from the weaker 1964 El Niño in that the northern radiolarian expatriates are dominated by California Current forms in the fossil (sedimentary) record of Santa Barbara Basin. The magnitude of these El Niños can also be distinguished from the recent (planktonic) or fossil (sedimentary) record by the provenances of the warm water radiolarians.

LATE QUATERNARY VEGETATION HISTORY OF THE SOUTHWESTERN U.S.: THE PACKRAT MIDDEN RECORD

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U.S. Geological Survey - Tucson, AZ

ABSTRACT

The southwestern U.S. is a semi-arid region where complex physiography and position relative to dominant air masses result in great climatic and biotic diversity. Evidence for plant distributions during the late Quaternary comes mainly from macrofossils embedded in packrat middens, indurated, uriniferous deposits that are ubiquitous in protected caves and rock crevices throughout the Southwest. Midden research since 1960 has contributed about 100 published papers, based on more than 1200 radiocarbon dates.

The rat's foraging range, less than one hectare, limits the source area for the plant macrofossils, which are usually identifiable to species. A single midden sample normally includes 20 to 30 plant species which grew concurrently during what is probably a relatively brief depositional episode of one to several years. Middens yield point-specific information about geographic ranges, including a plant's preference for elevation, rock type, and slope aspect through time. The higher taxonomic and spatial resolutions of this technique are a decided advantage over pollen analysis in the Southwest, where "regional" vegetation (sampled by pollen rain) is not uniform, but a complex mosaic on rugged topography that may include several ecologically-distinct species of indistinguishable pollen morphology.

Packrat middens are not free of bias, however. They are restricted to rocky environments, with other topography left unsampled. In the scarp woodlands of the Great Plains, middens would have no doubt missed the sea of grass for the few clumps of trees. Midden floras may reflect the food preferences of different packrat species, particularly as they affect the relative species abundance in middens. There are also serious limitations in temporal resolution. A time series spanning tens of thousands of years is constructed from stratigraphically-discontinuous spot samples, each snapshot representing one to several years and separated by unsampled intervals of centuries if not millennia. Subjectivity plays a major role in determining which middens are collected. Curiosity about vegetation patterns of the last glacial advance, which could be called "the lure of the Pleistocene," has conspired with natural decay of the fossil record with increasing age, or "the pull of the modern," to produce a bimodal age distribution in radiocarbon dates from middens, with sharp peaks at 10,000 and 0-1000 yr B.P.

In spite of the method's shortcomings, midden studies have made the southwestern U.S. the first arid region worldwide with a reasonably comprehensive record of vegetation history through the Pleistocene-Holocene transition. By way of introduction, the marine stratigraphic record for the last 2-million years indicates 16-18 prolonged (100,000 yrs) glaciations, punctuated by brief (10,000 yrs), warm interglacials like the present. There is little assurance that biotic changes on land have kept exact pace with the reiterations of the oxygen isotope curve from deep sea cores, or that vegetation patterns are necessarily duplicated in each glacial or interglacial period. Though we tend to view the present as the norm, modern vegetation patterns are probably ephemeral and unstable in the long term. For many plants, present range expansions and contractions may mark the progress of directional migrations over several millennia, rather than human impact or

random climatic variations about some long-term mean. A stable climatic mode on the scale of millennia is unlikely (e.g., orbital parameters controlling the distribution of sunlight on the earth's surface have yet to repeat themselves during the Holocene).

Because most range shifts in the Southwest can be expressed as changes in elevation, former plant distributions are best understood by considering large-scale patterns in physiography. The current upper limit of desert plants and lower limit of woodland trees is ca. 1500 m. The Chihuahuan, Sonoran, and Mojave deserts define extensive lowlands (< 1500 m) that terminate abruptly to the north in the transition to a regional platform (mostly above 1500 m) occupied by the Colorado Plateau and Great Basin. Hence, the northern limit of many desert plants is not a climatic but a physiographic boundary. Woodlands of great areal extent terminate along this topographic break, with isolated populations on the insular mountain ranges of the southern deserts. Another aspect of southwestern physiography important to reconstructing past vegetation is considerable regional variability in the relationship between a plants areal extent and elevation. On a conical mountain, a lowering in the range of a plant automatically implies an increase in its areal extent. On a high, steep-sided plateau, however, the most extensive areas are at the highest elevations, so that a depression of forests occupying the plateau summit could actually lead to a decrease rather than an increase in areal extent.

During the late Wisconsin, many southwestern plants occurred 500-1000 m below their present lower limits. In the Great Basin and Colorado Plateau, sagebrush steppe, subalpine woodlands and mixed conifer forests covered the large expanses now occupied by pinyon-juniper woodlands. Ponderosa pine is conspicuously missing from Pleistocene midden records in these areas and was probably displaced far to the south. Spruce-fir forest, normally the forest type at upper treeline, occurred as low as 2000 m, near the base of most of the principal ranges in the central and southern Rockies. This implies the displacement of other forest and woodland types now considered characteristic of the Rockies (e.g., as implied in common plant names such as Rocky Mountain juniper and Colorado pinyon). The lowlands in the southern deserts were clad in pinyon-juniper-oak woodlands; desert plant communities like those of today were restricted to the lower Colorado River Valley. Saguaros and paloverdes, the hallmark of Sonoran Desert vegetation, appear to be only recent (Holocene) immigrants to Arizona. The upper limit of pinyon-juniper-oak woodlands was ca. 1500 m, which fixed the woodlands' northern limits along the northern boundaries of the southern deserts.

To most authors, late glacial distributions reflect wetter winters and drier summers, congruent with reconstructed warming of the Pacific subtropical gyre in winter and cooling of the subtropical Atlantic in summer. Growing-season temperatures were probably 5-10 degrees (C) cooler than today. There is considerable disagreement as to whether annual precipitation was higher and winter temperatures lower than now. The most frequently cited explanation for milder winters involves the role of the ice sheets in blocking incursions of cold, Arctic air from entering the United States, principally that air flow from the ice caps would have been mostly katabatic.

The Pleistocene-Holocene transition was a dynamic period, when plants expanded or contracted their ranges dramatically in response to rapid warming and changes in the seasonality of rainfall. Data from some areas reflect sequential changes from 18,000 to 11,000 yr B.P. Other data suggest relative stability until 11,000 yr B.P. Enhanced monsoons and annual temperatures near the modern mean have been proposed for as early as 12,000 yr B.P. on the basis of midden data. This interpretation is supported by relatively heavy D/H isotopic values in plant cellulose from middens that date between 14,000 and 10,000 yr. B.P., but appear to conflict with the persistence of highland conifers at low elevations and the delay of most Holocene immigrations until after 10,000 yr B.P. As in the eastern U.S., major debate is focused on vegetational inertia (i.e., migrational lag) vs. a continually-changing climate to explain migrational patterns during the Pleistocene-Holocene transition. The principal question is the varying rates at which plants achieve migrational equilibrium after a major climatic change, and to what extent does this lessen the value of vegetation history as a proxy for paleoclimates.

Most paleoclimatic inferences drawn from former plant distributions are couched in terms of "average weather" conditions and seldom consider that plants do not experience mean climate, but are exposed to alternating sequences of growth and stress on both intra-annual and interannual scales. Plant distributional shifts generally involve establishment and mortality, which are sensitive to high-frequency variability in weather. A relatively new approach in paleoecology involves studies of how climatic variability over the past century has affected recent establishment and mortality of key plants to develop hypotheses about vegetation-climate dynamics in the fossil record. Although of smaller magnitude, these recent climatic and biotic changes can be treated as qualitative analogs to climatic and biotic regimes at other times during the late Quaternary. This approach, recently summarized by Neilson (1986), draws strength from the "teleconnected" aspect of global climate on various time scales. This is most evident in the apparent asynchroneity of wet-dry epochs (and individual years) between the southwestern U.S. and the Sahara Desert. When pluvial lakes were maintained in the southwestern U.S., African lakes were bone-dry; the last two decades were anomalously wet in the Southwest, quite dry in monsoonal Africa; and while the Southwest was besieged with catastrophic floods during the 1982-83 El Niño, the Sahel experienced pronounced drought. With this perspective, physiological ecology and synoptic climatology should continue to make significant inroads towards understanding climate-vegetation dynamics of the late Quaternary.

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VARIATIONS IN ANNUAL MASS BALANCE FOR SEVEN NORTH AMERICAN GLACIERS

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ABSTRACTS

The annual mass balance of a glacier is the difference between the net accumulation in winter, and the net loss during summer. The values used here are area-averages over each glacier and their magnitudes are of the order of meters/annum. The balances depend heavily upon precipitation and temperature in winter, and temperature and amount of insolation in summer. These meteorological variables are in turn influenced by the large-scale atmospheric circulation over the North Pacific Ocean. This study addresses the relation between mass balance and large-scale atmospheric effects.

The study area includes western North America from Washington to Alaska and from the coast to the Rocky Mountains. In this area, seven glaciers have sufficiently long time series for mass balance: two in Washington, three in Canada, and two in Alaska. This preliminary analysis uses 10 years of data (1971-80), and the final analysis will include 20 years of data (1966-85).

The similarities and the differences between the glaciers is brought out using empirical orthogonal function analysis. Eighty percent of the variance is contained in the first two empirical modes (60%, 20%). The first mode shows the negative correlation between the balances for Alaska glaciers and the remaining glaciers. This relation is due to the steering effect of the Aleutian low: when it is dry in Washington, it is usually wet in Alaska, and vice versa. The first mode also shows that dry conditions in Washington and wet conditions in Alaska are associated with El Niño-Southern Oscillation (ENSO) events. In addition, there was a bias introduced after the 1977 ENSO event such that the mass balances in Washington are more negative and those in Alaska are more positive than before.

This analysis will be pursued further using the 20-year data set when available. In particular, limited data indicates there were anomalous conditions during the 1982-83 ENSO event when there were large positive balances in British Columbia, but negative balances in both Washington and Alaska.

THE QUEST FOR UNDERSTANDING AND PREDICTION OF SOME SHORT-PERIOD CLIMATE FLUCTUATIONS

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ABSTRACT

This paper was somewhat eclectic in that the author tried to show how extremes of weather and climate, particularly relevant to precipitation, are manifestations of the general circulation of the atmosphere, which in turn owes some of its behavior to the underlying temperature patterns of the sea surface. The report did this largely through examples of extreme cases. Among these are the recent spell of several years of heavy precipitation leading to high levels of Great Salt Lake and the Great Lakes, heavy precipitation or drought regimes over southern California, El Niño effects, and the degree of persistence of sea surface temperature and atmospheric circulation patterns over spells of years and even decades.

The physical causes of these phenomena appear to lie largely in anomalies of the atmospheric midtropospheric circulation, the abnormalities of the underlying surface, and importantly, in the amazingly reliable teleconnections (cross-correlations) found between parts of the atmosphere, separated by thousands of kilometers, or between latitude belts from the tropics to polar latitudes. Fortunately, catalogues of these teleconnections, stratified by season, are now available from a forty year record of maps and with the indispensable use of computers. Similarly, it is now possible to specify sea surface temperatures from atmospheric circulations for time scales of months, seasons and years, as well as to specify atmospheric circulation from ocean temperatures.

Also described were patterns of air and sea over the North Pacific that are apt to persist longer than others--depending upon time of the year, magnitude of anomalies, and character of pattern. Thus, persistence itself is a climatic variable, with both high and low frequency modes.

Finally, some of the above concepts were applied to the period 18,000 BP in order to suggest storm patterns and moisture sources that may have prevailed during the last major glaciation.

CLIMATE AND FISHERIES: CAUSE AND EFFECT
LONG AND SHORT TERM PATTERNS AND PROCESSES

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ABSTRACT

Fisheries and society have clearly been shaped by both long and short term climate and weather patterns, on local, regional and global scales. The recent convergence of many research sciences on these climate-driven processes has made it possible to begin to attribute many of the various responses to common causal climate patterns. Among the most recent popular issues has been the study of El Niño, and the overwhelming relations between ENSO and global and regional events, particularly with respect to fisheries and flood/drought cycles.

While there have been paleo-sediment samples collected from around the world, most analyses have been on long (20,000 year or more) scales. The recent flurry of concern over man induced greenhouse gas and global warming has focused much more on the decadal to century time scales, and this has promoted the collection and/or reanalysis of existing materials on these more dynamic and societally germain scales. Among the more esoteric correlations are that the extreme climatic events that are observed, such as flooding of the American southwestern desert areas, snowfalls in Los Angeles basin, Australia's immense grass fires, severest Indonesian and Kenyan droughts, maxima of per capita heating oil consumption, frequencies of intense El Niño events, and the bottom up Shumpter economic cycles appear to co-occur with the peaking of sardine populations, and catches of sardines around the Pacific Basin.

The cyclical sardine population processes involved have analogs in the Benguela Current System, and appear to be related to periods of positive heat input into the near shore transition zones from general equatorial watermass heating. There are innumerable local weather and biological patterns which reflect these longer term processes. On the shorter term erratic weather and strong local anomalies form the critical events that are concentrated within these heating periods. The larger scale changes in rainfall and seasonal weather patterns lend themselves to parallel economic variabilities that are felt on a global scale, likely forming the basis of the Shumpter cycle, as well as the need for periodic readjustments of fuel requirements, hence the recently described fuel innovation cycles.

On the longer time scales, there are clear sedimentary record of similar climate patterns and biological responses that cycle quasi periodically for the last several millenia, particularly in varved sediments from the anoxic basins and coastal zones of the eastern boundary current regions. Recent studies of long ice cores and paleolimnological information from the periferies of the Pacific Basin offer greater opportunity than ever before to relate local climatic changes with ENSO, global climate patterns, and biological responses.

The apparent sensitivity of marine populations to these sequences of climatic processes has perhaps provided a strong inferential signal from which both intra-annual and decadal changes can be forecast with some certainty, in contrast to the present technical capabilities. This will become much more valuable within the next decades as the human population increases from its present levels of five billion.

A REVIEW OF CIRCULATION AND MIXING STUDIES OF SAN FANCEISCO BAY

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A description of the major features and remaining unknowns of circulation and mixing in San Francisco Bay has been constructed from a review of published studies. From a broad perspective San Francisco Bay is an ocean-river mixing zone with a seaward flow equal to the sum of the river inflows. Understanding of circulation and mixing within the Bay requires quantification of freshwater inflows and ocean-bay exchanges, characterization of source-water variations, and separation of the within-Bay components of circulation and mixing processes. Description of net circulation and mixing over a few days to a few months illustrates best the interactions of major components. Quantification of tidal circulation and mixing is also necessary because net circulation and mixing contain a large tidal component, and because tidal variations are dominant in measurements of stage, currents, and salinity.

The discharge of the Sacramento-San Joaquin Delta into Suisun Bay is approximately 90 percent of the freshwater inflow to San Francisco Bay. Annual Delta discharge is characterized by a winter season of high runoff and a summer season of low runoff. For the period 1956 to 1985 the mean of monthly discharges exceeded 1000 m^3/s (35,000 ft^3/s) for the months of December through April, whereas for July through October, it was less than 400 m^3/s (14,000 ft^3/s). The months of November, May, and June commonly were transition months between these seasons. Large year-to-year deviations from this annual pattern have occurred frequently.

Much less is known about the ocean-bay exchange process. Net exchanges depend upon net seaward flow in the Bay, tidal amplitude, and longshore coastal currents, but exchanges have not been measured successfully yet. Source-water variations are ignored by limiting discussion of mixing to salinity.

The Bay is composed of a northern reach, which is strongly influenced by Delta discharge, and South Bay, a tributary estuary which responds to conditions in Central Bay. In the northern reach net circulation is characterized by the river-induced seaward flow and a resulting gravitational circulation in the channels, and by a tide- and wind-induced net horizontal circulation. A surface layer of relatively fresh water in Central Bay generated by high delta discharges can induce gravitational circulation in South Bay. During low delta discharges South Bay has nearly the same salinity as Central Bay and is characterized by tide- and wind-induced net horizontal circulation.

In the northern reach a non-tidal current null zone moves rapidly seaward in response to increases in Delta discharge, and after runoff events returns landward over a few months. During the low-discharge period the northern reach achieves an approximate salt balance in 2 to 3 months. The mean residence time in the northern reach is a few days during high discharges and of the order of 2 to 3 months during low discharges.

In South Bay evidence suggests 3 distinct mixing zones separated by San Bruno Shoal and a constriction at the San Mateo Bridge. These mixing restraints combined with relatively small local inflows cause the mean residence time to be of the order of months during the low-discharge season. When gravitational circulation penetrates these zones during high discharges, the mean residence time is reduced to less than a month. Initially the gravitational circulation is southward at the surface and northward at the bottom, and reverses after runoff subsides when reintrusion of ocean water through the Golden Gate raises salinities in Central Bay.

Tides and tidal currents are dominant features of the Bay. The Bay has two distinct high and low tides during each 24 hours and 50 minutes, a noticeable spring-neap cycle twice each month, and seasonal variations in the spring-neap cycle. High tide at the Golden Gate takes 1 to 1.5 hours to reach the southern end of South Bay and 3 to 3.5 hours to reach the landward limit of Suisun Bay. The tidal range at the Golden Gate of about 2 m (6.5 ft) is reduced by about 30 percent in the northern reach and amplified by about 60 percent in South Bay. Typical tidal currents range from about 20 cm/s (0.7 ft/s) in the shallows to more than 100 cm/s (3 ft/s) near the surface in the channels. Maximum tidal currents in South Bay occur at about mid-tide and slack water near the tide extremes (high or low), whereas in the northern reach maximum currents occur before tide extremes and slack water 1 to 2 hours after extremes.

The need to quantify important features of circulation and mixing suggests a need for additional study. Gravitational circulation in the northern reach and horizontal circulation in Central and San Pablo Bays have not been examined in detail. The exchange process between Central and South Bays has not been quantified yet. Estimation of residence time distributions, particularly the differences between channels and shallows, requires further work. Measurements of net delta discharges, quantification of the ocean-bay exchange process, and additional measurements of currents in the large shallow areas of the Bay are needed to address many questions.

CLIMATE RECORDS IN CALIFORNIA LAKE SEDIMENT

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ABSTRACT

Most PACLIM investigations deal with time spans that are quite short in geological terms. Although studies of past climates preserved in lake sediments are usually concerned with much longer intervals, they are important as a background to more detailed studies of the modern environment. Such records establish the range of variability that has occurred in the geologically recent past and can hence be reasonably expected in the future. Four California pollen records spanning intervals from 3 ka to 3 Ma are discussed as examples.

The pollen record from Pearson's Pond on the San Francisco Peninsula spans the past 3 ka (Adam, 1975). The pond sits atop a landslide and is ephemeral, but changes in the abundance of the algae _Pediastrum_ and _Botryococcus_ with depth suggest that the pond has stayed wet later in the summer during at least two intervals during the past 3 ka. Even within the upper Holocene, the climate of the California coast has been wetter and/or cooler than at present.

At Laguna de las Trancas, on the California coast just north of Monterey Bay, another landslide pond contains a pollen record for the past 30 ka (Adam and others, 1981). That record documents the occurrence of true fir (_Abies_) growing along the coast in that area during the last full glacial period. The region is well outside the present range of any of the true firs.

The pollen record from Clear Lake, about 155 km north of San Francisco, spans the complete last glacial cycle (the past 130 ka) and is one of the longest records yet studied on the West Coast. Among the most striking features of the Clear Lake record is a series of climatic oscillations during the interval from about 120 ka to 70 ka. The Clear Lake oscillations correlate remarkably well with similar oscillations observed in Europe and in deep-sea oxygen-isotope records. This interval represents the climatic regime that immediately followed the end of the last interglacial period and is thus the natural regime most likely to develop when the present interglacial period ends. The abruptness of some of the changes observed early in the last glacial cycle, as well as the repeated oscillations between relatively cool and relatively warm conditions, suggest a global climatic regime distinctly different than the present one. The relevant implication for PACLIM is that short-term modern studies may fail to detect important modes of behavior of the climate system that will probably influence future climates.

A 334-m core from Tulelake, near the Oregon-California border in eastern Siskiyou County, has demonstrated the possibility of recovering mostly continuous stratigraphic records extending from the present back for several million years (Adam and others, 1986b, in press). Many of the tectonic basins in the western United States appear to be suitable sites for the recovery of such cores. In some regions, particularly in the northwestern Great Basin, nearby volcanic vents may provide numerous tephra (volcanic ash) layers that can permit detailed correlations between records at many time horizons. The Tulelake core, for example, contains 12 identified silicic tephra that have been correlated with other sections both in the western United States and in

Deep Sea Drilling Project cores. Even in the absence of tephra layers, the paleomagnetic record in long cores can provide reliable correlations between sites. Such work will require significant fieldwork and sample curation operations, as well as cooperative interdisciplinary investigations. The payoff will be a greatly improved understanding of how our present climate system has evolved, how much variability we can expect of it, and how the continuous climatic records already well described from deep-sea cores relate to the climatic history of the continents.

For PACLIM, the long-term climatic studies referenced above provide the context within which shorter-term studies are set. Without an adequate understanding of context, neither the full implications nor the limitations of detailed studies can be completely appreciated.

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RESPONSE OF SUBARCTIC SILICEOUS PLANKTON FLUXES TO THE 1982-1983 EL NIÑO

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ABSTRACT

Biweekly time-series sediment rap samples were collected by the PARFLUX Program at Station PAPA (50ON, 145OW; water depth 420 m) in the northeastern North Pacific. The samples were collected continuously for two years (September 1982-August 1984) at 3800 m and for a half year (March-September 1983) at 1000 m. Composition of biogenic opal shells was studied in order to understand the extent of temporal flux variability which could account for changes in surface productivity of the oceans. Among the opal components, diatoms as a group dominated the fluxes throughout the study period, followed by radiolarians and silicoflagellates in terms of opal mass.

Based on flux maxima, minima, and species components from 1000 m and 3800 m, autocorrelations showed that the two samples were generally offset by one sample interval of two weeks. The sinking speeds of most siliceous species are thus estimated to be approximately 175 m/d^{-1} regardless of taxa, size, or morphology, invoking the necessity of aggregated and accelerated sinking. Fluxes of various taxa measured at 1000 m and 3800 m with one sample offset generally were nearly equal, implying that no significant dissolution occurs en route to the sea floor.

Nearly all species of diatoms, silicoflagellates, and radiolarians showed a significant decrease in annual cumulative flux at 3800 m from year 1 (September 1982-August 1983) to year 2 (September 1983-August 1984). Seasonal flux patterns of most species were also significantly different from year 1 to year 2 (Fig. 1). These interannual changes were probably related to the 1982-1983 El Niño, indicating subarctic hydrographic and planktonic responses approximately one year later than the low latitude event. Notable changes in hydrography of the upper 100 m were observed. During the low flux period in year 2 the density of upper water layers were more stable than during normal periods. This caused much less mixing of subsurface water to the euphotic zone and hence prevented a good nutrient supply to the mixed zone.

Species fluxes of all three siliceous plankton groups responded to these drastic environmental changes possibly caused by the 1982-1983 El Niño. Degrees and patterns of flux response by each species often are different depending on their position in the ecosystem. There are enough signals to enable us to monitor climatic changes imprinted on siliceous plankton shall fluxes in pelagic realms. Particularly, application of this technique to the paleoenvironment is promising since these siliceous shells have been preserved in the sedimentary record.

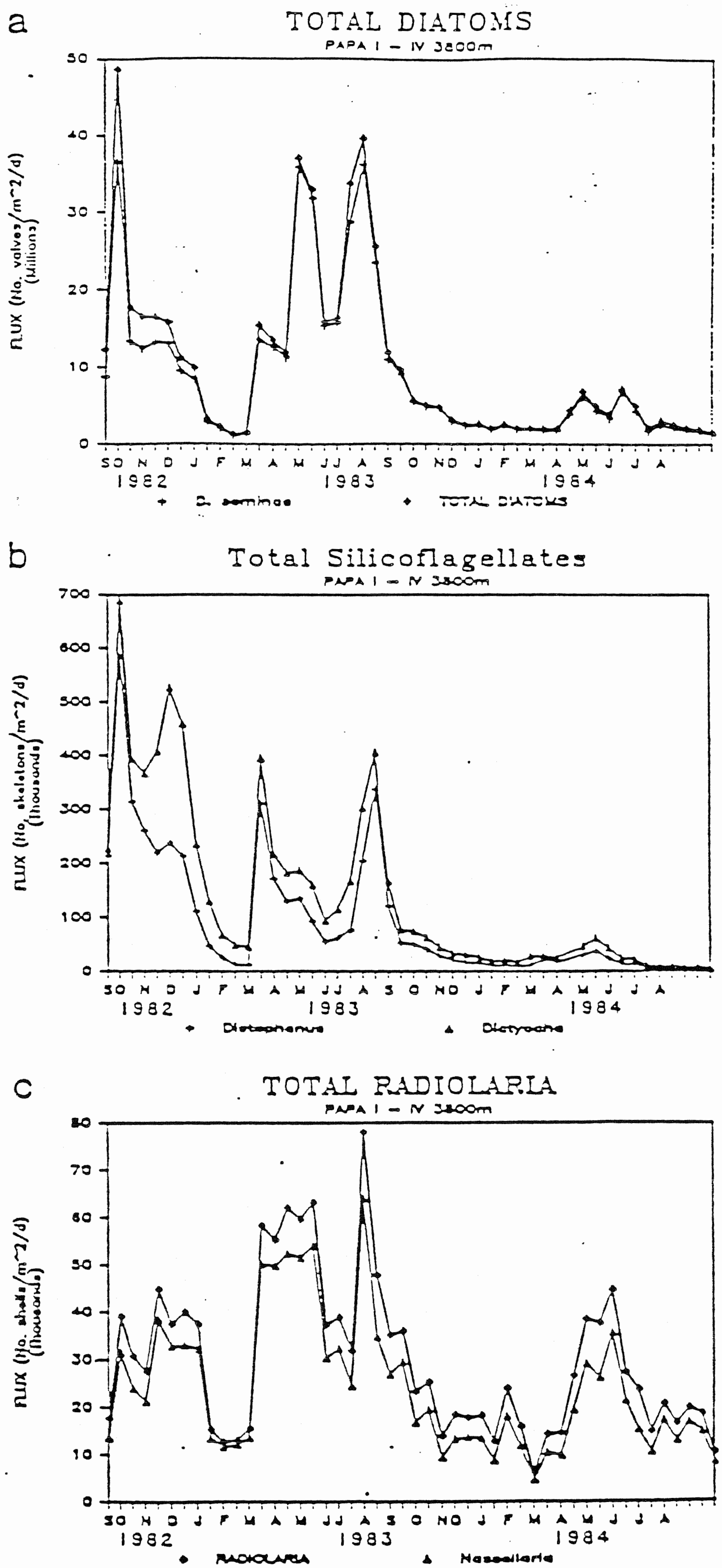
a
TOTAL DIATOMS
PAPA I – IV 3800m
FLUX (No. valves/m^2/d) (Millions)
0
10
20
30
40
50
SO N D J F M A M JJ A S O ND J F M A M J J A
1982
1983
1984
D. seminae
TOTAL DIATOMS
b
Total Silicoflagellates
PAPA I – IV 3800m
FLUX (No. skeletons/m^2/d) (thousands)
0
100
200
300
400
500
600
700
SO N D J F M A M JJ A S O ND J F M A M J J A
1982
1983
1984
Distephanus
Dictyocha
c
TOTAL RADIOLARIA
PAPA I – IV 3800m
FLUX (No. shells/m^2/d) (thousands)
0
10
20
30
40
50
60
70
80
SO N D J F M A M JJ A S O ND J F M A M J J A
1982
1983
1984
RADIOLARIA
Nassellaria

Fig. 1

HISTORICAL CHANGES IN STREAMFLOW AND SEDIMENT DISCHARGE IN THE COLUMBIA RIVER

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ABSTRACT

Comprehensive maps of shoaling and erosion for two time periods (1868-1935 and 1935-58) and less complete maps for various shorter intervals show that the major changes in Columbia River Estuary bathymetry were coincident with installation of the jetties at the entrance (1885-1939) and constraint of the flow by pile dikes throughout the lower river and estuary (about 1910-1940). Although regulation of riverflow by dams began in the last century, it began to have a substantial effect on the seasonality of the riverflow only in the 1950's and to effect significant interannual transfer of flow in the late 1960's. Flow regulation may be excluded then, as a major contributor to the observed historical changes. Irrigation began about 1840 and reached nearly half its present level of development by 1930, but is believed to involve smaller volumes of water than the flow regulation. It may, therefore, be excluded as a major agent of change during the early decades of the century. Diking and filling have reduced the tidal prism of the system by about 15%, but most of this change also occurred after the period of maximum historical change in the interior of the estuary. The pattern and timing of the observed bathymetric changes strongly suggest that they result primarily from navigational improvements to the system.

To confirm inferences drawn from the maps, a sediment budget for the post-1868 period is being constructed. A streamflow-sediment discharge function defined from U.S. Geological Survey streamflow data at The Dalles (1878-to date) and sediment discharge measurements (1964-70) has been used to hindcast separately discharge of sand and of fine material (silt plus clay) back to 1878, under the assumption that land use changes have not altered sediment input. As riverflow increases to freshet levels, sand becomes the dominant component of sediment transported. The sediment input to the system during the late 19th century was much greater than at present, because the sediment transport increases as a high power of stream flow, and because peak riverflows were substantially greater at that time. A definitive artitioning of changes in transport caused by human influence and by climatic effects has not been achieved, but climatic effects are definitely important before about 1950 and are clearly overwhelmed by human intervention in the later part of the record.

OCEAN CLIMATE INFLUENCES ON ROCKFISH RECRUITMENT

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ABSTRACT

Understanding environmental processes affecting recruitment of young fish to commercially important fish stocks is a fundamental objective of fishery research. Methods have been developed for documenting ocean climate shifts and relating these shifts to changes in recruitment success of Widow (S. entomelas) and chilipepper (S. goodei) rockfish. Recruitment success is inferred from otolith aging of commercial catch samples. Climatic shifts in the physical environment are shown by a combined index derived from seven well defined physical measurements relevant to the rockfish habitat. The major results that have been developed so far are as follows:

1. Widow rockfish recruitment is favored by winters with deep Aleutian Lows, violent winter storms on the coast, above average sea temperatures, enhanced northward flow in the California Current and anomalously high coastal sea level. The Aleutian Lows that expand over the coast and bring frequent winter storms with strong winds from the south to intensify coastal ownwelling seem more important than the California El Niño alone in enhancing widow rockfish recruitment.

2. Chilipepper rockfish recruitment appears to be facilitated by cool water, and increased southerly California Current flow conditions. Exceptionally good chilipepper recruitment does not occur in years of exceptionally good widow rockfish recruitment.

3. The coastal ocean from central California to Vancouver Island has undergone three substantial climatic shifts in the 1965-1980 period. First, there was a warm period of five years which included two California El Niños and two Aleutian Low events. This period favored widow rockfish recruitment. After 1970 a shift to an ocean climate of cool sea temperatures and increased southerly flow in the California Current occurred. This cool period lasted until 1976 and included all the most numerous chilipepper rockfish cohorts contributing to the 1978 to 1983 catch. In 1976 the ocean climate shifted back to the warmer regime, favorable to widow rockfish recruitment.

Since the processes represented by the combined index represent the fundamental known sources of California Current variability, it is likely that other commercially important marine species will have recruitment success during environmental conditions that can be linked to the same patterns of climate fluctuation.

PACIFIC EOLIAN RECORD OF LATE PLEISTOCENE ATMOSPHERIC CIRCULATION

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ABSTRACT

Wind blown dust deposited in the deep sea provides a dual record of past climatic processes. The mass flux, or supply, of dust to the sediments is directly related to the aridity of the eolian source region. After the first few thousand kilometers of transport, the suspended dust achieves a grain size distribution in equilibruim with the energy of the transporting winds so the size of these equilibruim grains provides a proxy for wind intensity. We have determined these eolian size and flux parameters for a series of 6 deep-sea cores which form a north south profile from 28*0* to 45*0*N along about 160*0*E. The cores were sampled at 6,000-year intervals to provide a history of Asian aridity and the zonal westerlies for the past 30,000 years. Dust flux values along this profile show: relative minima at 18,000 years ago and the present, a flux maximum at 6,000 years ago, and that, along the profile, the latitudinal position of the flux maximum has remained unchanged at 38*0* to 40*0*N. The grain size of the eolian minerals mimics the present average position of the jet stream which varies anually between 30*0* and 40*0*N, in that sizes become finer north of 40*0*N. Through time this size gradient occurs at about 44*0*N at 6,000 years ago, 40*0*N at 12,000 years ago, and an undefined amount south of 37*0*N at 18,000 years ago. These data suggest that the Gobi-Mongolia region of Asia was relatively more humid at the height of the last glaciation and most arid 6,000 years ago, the sampled time closest to the mid-Holocene climatic optimum. The latitudinal position of the northern margin of the westerlies jet retreated poleward with glaciation reaching its northernmost extent during the time of greatest northern hemisphere warmeth 6,000 years ago and has shifted south since then.

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COMMENTS ON CLIMATIC RECORDS RELATED TO BIOGENIC SEDIMENTATION IN THE SANTA BARBARA BASIN

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ABSTRACT

While the interannual pattern of rain fall is the dominant factor in determining the year to year thickness of sediment laminae in the Santa Barbara Basin, its is the biologic record (shelled plankton etc.), lying within these annual layers that is of most interest.

The actual selection from a limited set of climatic information provides a fixed view of climate that likely differs from the real climate (see table). Inherent in the selected climatic series are relationships that may or may not reflect causation, but will, in any case, tend to emerge in subsequent analysis.

Using rank correlation, an unrestricted distribution comparison method, southern California July-June rainfall appears to have been marginally related to several of the selected climatic series. These relationships are shown by means of a "florogram," a nondistorted graphic representation of the correlation coefficients (see figure).

FLORO19.WRD

CORRELATION FLOROGRAM of SOUTHERN CALIFORNIA RAINFALL with SELECTED CLIMATIC SERIES

```
                                              rank correlation coefficient
         -.5       -.4       -.3       -.2       -.1        0        .1        .2        .3        .4        .5        .6
          +---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+

                                                                                 +[Cal. SNL temp. Oyr
                                                                                 |        +[Cal. SNL zoo. +lyr
             S. Cat. WNT ssT -2yr]+                                              |        |  +[Cal. Crnt. SNL trans. -2yr
                                  |                 SOUTHERN   CALIFORNIA        |        |  |     +[Cal. SNL zoo. -lyr
Scripps Pr. SNL sal. Oyr]---------------- - - - - - - - - - - - - - - - - - - ---------------------[S. Fran. SNL sea lev. Oyr
                 S. Oscill. SNL Oyr]+           SEASONAL (July-June) RAINFALL    |        |  |   +[Cal. SNL zoo. -2yr
                                                                                 |        | +[S. Nic. SNL upwell. +2yr
                                                                                 |       +[S. Nic. SNL upwell. +lyr
                                                                                 +[S. Diego SNL sea lev. Oyr

          +---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
         -.5       -.4       -.3       -.2       -.1        0        .1        .2        .3        .4        .5        .6
```

This florogram is a representation of rank correlation coefficients between selected climatic series over a plus and minus 2 year time span. The stem of the florogram is the southern California seasonal rainfall series. The other selected series are California seasonal temperature, Santa Catalina Is. winter sea surface temperature, Scripp's Pier seasonal surface salinity, San Francisco seasonal sea level, San Diego seasonal sea level, Southern Oscillation seasonal (after P. Wright), San Nicolas Is. seasonal upwelling (after A. Bakun), California Current seasonal transport (after P. Bernal) and California seasonal zooplankton biomass (after P. Bernal).

It is noted that for the rank correlation coefficient r, +1 represents perfect agreement, 0 no agreements, -1 perfect disagreement and (r^2) is a measure of variance explained.

CLMTNMS.WRD

SELECTED "CLIMATIC" RECORDS RELATED TO BIOGENIC SEDIMENTATION IN THE SANTA BARBARA BASIN

INSTRUMENTAL RAINFALL:
Southern California region 1851-1969; Santa Barbara region 1868-1969; Los Angeles region 1872-1969;
San Bernardino region 1868-1969; San Diego region 1851-1969

INSTRUMENTAL TEMPERATURE
California land/sea region (rain year) 1853-1970
winter; spring; summer; autumn 1852-1970
Santa Catalina Is. region sea surface "winter"; "spring"; "summer" 1923-1972

INSTRUMENTAL SALINITY
Scripp's Pier sea surface (rain year) 1917-1984
winter; spring; summer; autumn 1916-1984

INSTRUMENTAL SEA LEVEL
San Francisco (rain year) 1855-1970: winter; spring; summer; autumn 1854-1970
Los Angeles (rain year) 1925-1969: winter; spring; summer; autumn 1924-1969
San Diego (rain year) 1907-1969: winter; spring; summer; autumn 1906-1969
Hawaii (rain year) 1906-1970: winter; spring; summer; autumn 1905-1970

SOUTHERN OSCILLATION INDEX (after Wright)
rain year 1852-1974
winter; spring; summer; autumn (n. hemis.) 1851-1974

UPWELLING (after Bakun)

San Nicolas Basin region (rain year) 1947-1971
winter; spring; summer; autumn 1946-1971

INTEGRATED TRANSPORT (after Bernal)
Pt. Conception 1950-1970

HISTORICAL EL NINO (after Quinn)
South America 1760-1976

TREE GROWTH
San Jacinto biconoe spruce 1385-1850; San Gorgonia Pinus flexis 1670-1970
White Mountain bristlecone pine (short series) 1600-1963

RAINFALL PROXY by TREE GROWTH (after Michaelson)
Santa Barbara 1600-1985

RAINFALL PROXY by MISSION HISTORICAL RECORDS (after Lynch)
Southern California 1770-1850; Santa Barbara 1851-1867; Los Angeles 1770-1871; San Diego 1801-1850

SEA SURFACE TEMPERATURE PROXY by TREE GROWTH (after Douglas)
"winter"; "spring"; "summer" 1671-1963

ENSO INDEX PROXY by TREE GROWTH (after Michaelson)
SW U.S.& N. Mexico 1570-1964

ZOOPLANKTON ABUNDANCE (after Bernal & CalCOFI)
California coast (rain year) 1949-1970; Central California coast (rain year) 1949-1970
Southern California coast (rain year) 1949-1970; Northern Baja California coast (rain year) 1949-1970

SEDIMENT CHEMICAL PARAMETERS (after Dunbar)
Carbonate 1784-1978 (>2yr increments); Oxygen-18 1784-1978 (>2yr increments)
Carbon-13 1784-1978 (>2yr increments)

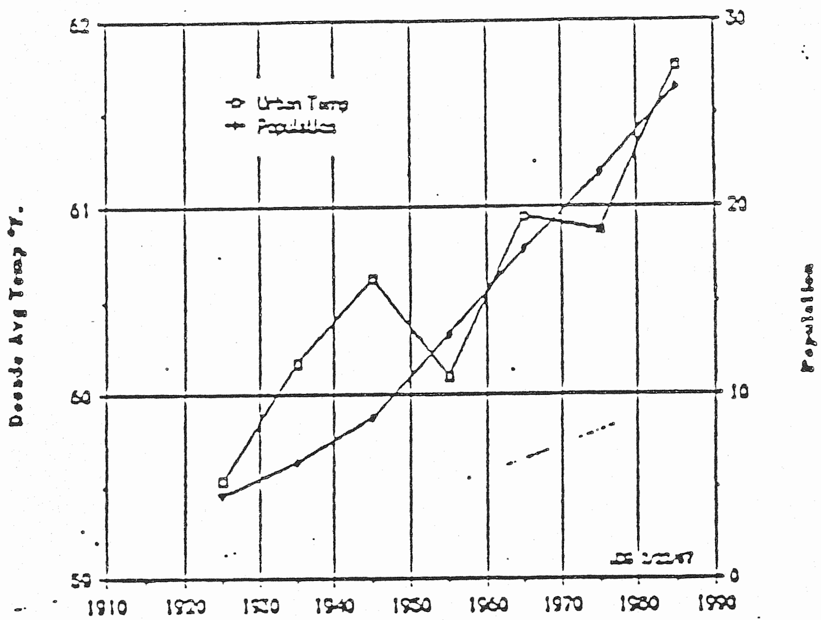
SEDIMENTATION
Varve thickness 1824-1966

PAPER PREPARED FOR 1987 PACIFIC CLIMATE WORKSHOPS
Asilomar Conference Center, Pacific Grove, CA,
March 22-26, 1987
(Dr. Goodridge was unable to attend the workshop because of another commitment and asked that his paper be included for information)

POPULATION AND TEMPERATURE TRENDS IN CALIFORNIA

James Goodridge
Chico, CA

Population and Urban Temperature Trends



Atmospheric carbon dioxide (CO_2) as measured at Mona Loa in Hawaii has been showing a steady increase since it was first measured in 1958. In absolute terms the amount of atmospheric CO_2 is quite small as is its annual increase as shown on Figure 1. The view we commonly share of the CO_2 build up is that of Figure 1c, where a very small value is greatly amplified. The real cause for concern is that annual rate of increase in atmospheric CO_2 is accelerating, as shown in Figure 1b.

The temperature data of the world has shown a steady increase in long-term trend in both the northern and southern hemispheres according to Jones et al. There is a large literature accumulating on the effects of an atmospheric increase in carbon dioxide (Thompson and Schneider, 1982; Madden and Ramanathan, 1980; Wigley and Jones, 1981; Manabe and Wetherald, 1980; Hansen et. al., 1981) and a severe lack of detailed inquiry into the exposure of the thermonmeters on which surface air temperature observations are based.

This writer feels that a real atmospheric "greenhouse effect" resulting from a CO_2 buildup would cause long-term temperature increase equally in urban and rural areas. There is a large difference between the temperature trends of urban and rural locations in California. It is only the urban temperature records which show a long-term increase in temperature. The urban heating seems to be a result of urban air and/or thermal pollution rather than an atmospheric CO_2 buildup effecting the entire atmosphere.

The population of California has grown by a factor of about 10 in the last 70 years. The population growth has been in the urban centers. The urban temperature records of California almost without exception show a temperature trend which correlates with population growth in the state.

This paper summarizes the long-term trends in 74 temperature records in California as shown on Figure 2. The averages of all of the long-term temperature records that were found for the State of California, that were complete for the 70 years base period from 1916 to 1985, are included in this study. The man annual temperature for these 74 records are tabulated on Table 1 for each year of record. The station locations are plotted on a map of the state shown here as Figure 3.

All of the 74 records are from the National Weather Service and most of them were published in Climatological Data for California. The mean annual temperature, as used in this study, is the average of the 12 monthly means which is the average of the maximum and minimum temperature for each day of the month. This has been the standard method of computing the mean monthly temperature in the U.S. weather establishment since about 1910.

The 74 records were divided into two groups representing those records which show the strongest urban warming trend and those which are more representative of the rural environment. Decade mean temperature for seven 10-year periods are listed on Table 2 along with the regression analysis showing time variation of temperature. Those records classified here as rural representing rural environments are arbitrarily selected as those with a slope (B) of the regression analysis less than .0125.

There is an unusual occurrence of an urban station, specifically San Francisco, in the list of rural stations. Apparently San Francisco's well ventilated geography is responsible for this. Vancouver, British Columbia, is another well ventilated coastal city where the sea water and air temperatures are highly correlated and no long term upward temperature trends are apparent.

The Mount Hamilton station on the top of an isolated mountain is listed with urban stations. This is because the thermometer shelter at Mount Hamilton is only a few feet lower and about 100 feet south of a large chimney where the domitories and offices associated with the astronomical observatory are heated. One can almost tell in what years the facilities were used by noting the departures from average temperature at Mount Hamilton. In general the classification of the temperature records as urban or rural is fairly close to reality as the writer knows it from viewing most of the sites.

The average annual temperature for all of the 39 rural and 35 urban sites is plotted on Figures 4 and 5. The same data are plotted on Figures 21 and 22 as a fraction of the average annual value. The annual difference between the urban and rural temperatures is plotted on Figure 23. The average of the 35 urban temperature records clearly shows an increasing trend with time where the average of the 39 rural records has a slight decreasing trend in the 70-year study period. Sometimes the annual values obstruct the vision and the trends can be seen more clearly with running averages as shown on Figure 6. In this study, since a large mass of data is being examined, decade averages are used to simplify the long-term trends in the data sets as in Figure 7.

The population of California has increased from 2.9 to 26.4 over the time of this study. The population data of this study are listed on Table 3, and shown graphically on Figure 8. The rate of change in population of California as modeled by a straight line regression analysis is listed on Table 4 for each county in California. The location of the boundaries of California counties is shown on Figure 9.

Decade averages of urban temperatures were found to be highly correlated with total state population. This is illustrated on Figure 10. The decade average rural temperature was found to be poorly and negatively correlated with statewide population as illustrated on Figure 11. The strong linear trend found in the urban temperature and population curve (Figure 10) is reflected in the temperature trend curve shown on Figure 12. The temperature and population trends are compared on Figure 13. No similarity exists between the rural temperature and the population as shown on Figures 13 and 14.

Good temperature records are highly correlated. One data set which seems ought to be free of the effects of nearby incinerators and other waste heat sources is the west coast sea surface temperatures (SST). The decade averages of SST are shown on Figures 15 to 18. The long-term trends in SST looks a lot like the long-term trends in the rural temperature records as shown on Figure 7. The two seawater temperature stations which are noticeably different are Astoria and San Francisco. This could possibly reflect coastal upwelling of ocean currents or the outflows of nearby rivers.

British Columbia air temperature records are compared with sea surface temperature records on Figure 19. The similarity in long-term trends in sea and air temperature is remarkable.

Jerome Namias from Scripps Institution of Oceanography at La Jolla, California, has suggested that the reason for the high sea surface temperatures in the decade ending in 1985 is higher than average westerly winds in the tropical Pacific Ocean during this decade. This would cause the sea levels to be higher on the west coast of North America and result in less cold water upwelling in the ocean along the coast. This is illustrated by the high value of winter westerly wind at 700 mb in the subtropical Pacific Ocean as reported by Namias and shown here as Figure 20.

A 1986 temperature study by Diaz shows long-term trends in northern North America which resemble those of rural California and not those of urban parts of the state as found in this study.

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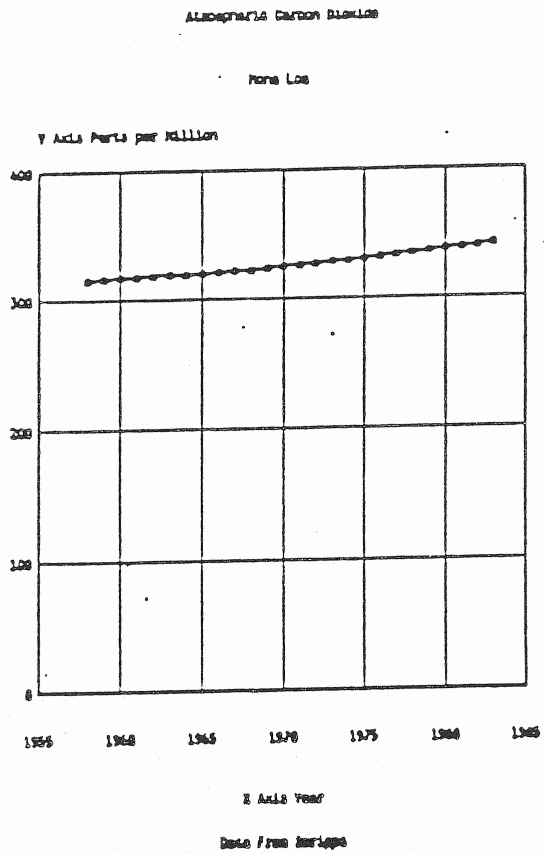


Figure 1a

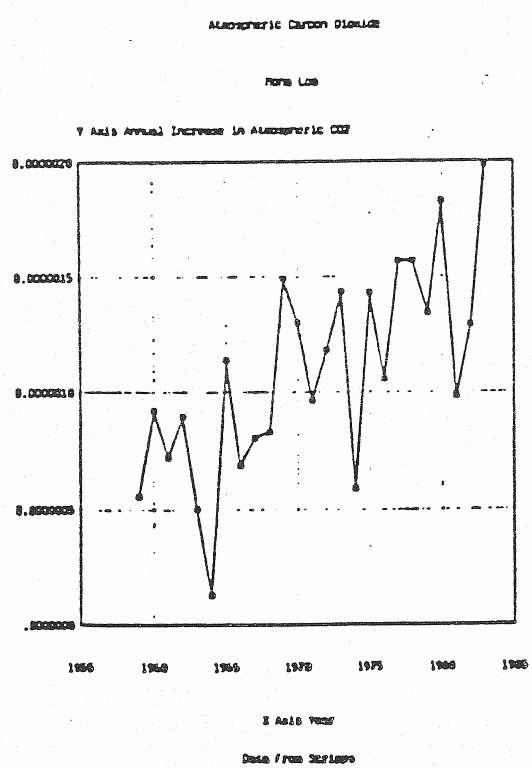


Figure 1b

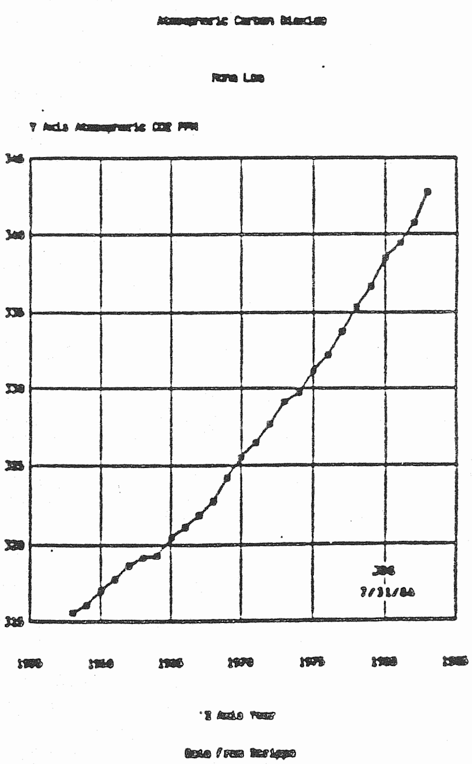


Figure 1c

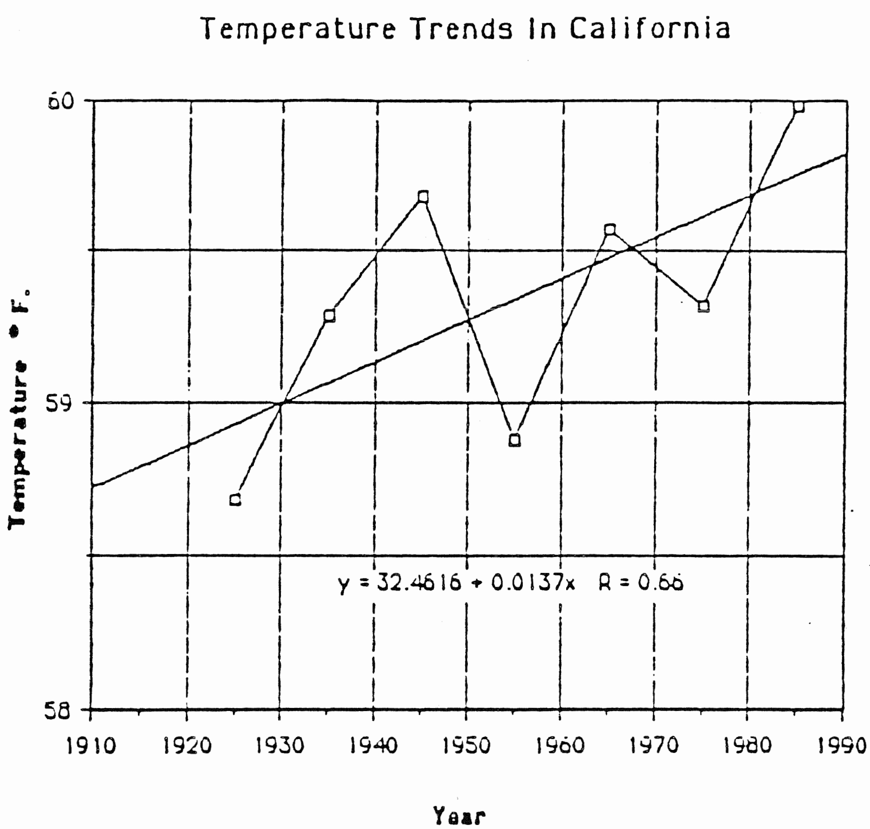
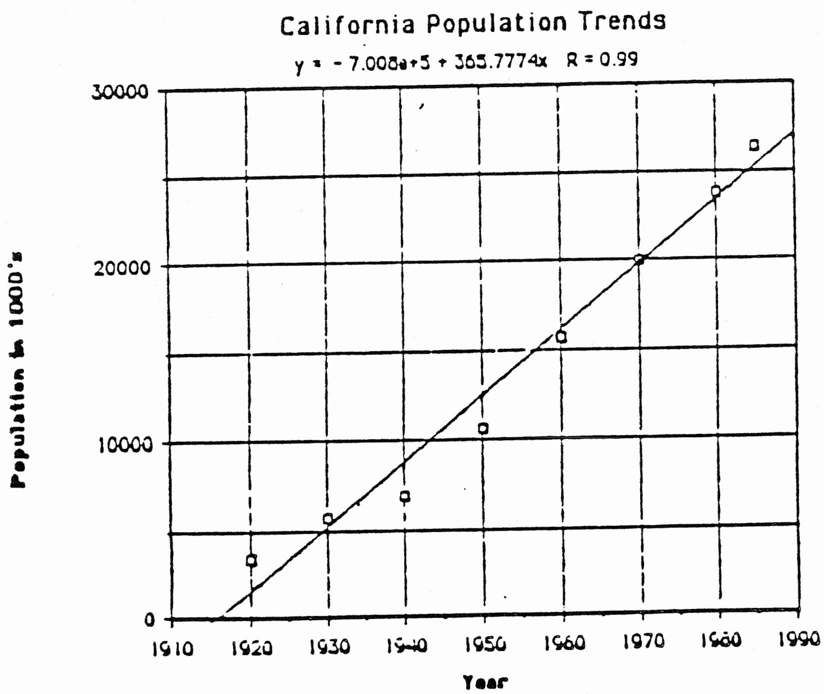


Figure 2



$y = -7.008e{+}5 + 365.7774x \quad R = 0.99$

Figure 8

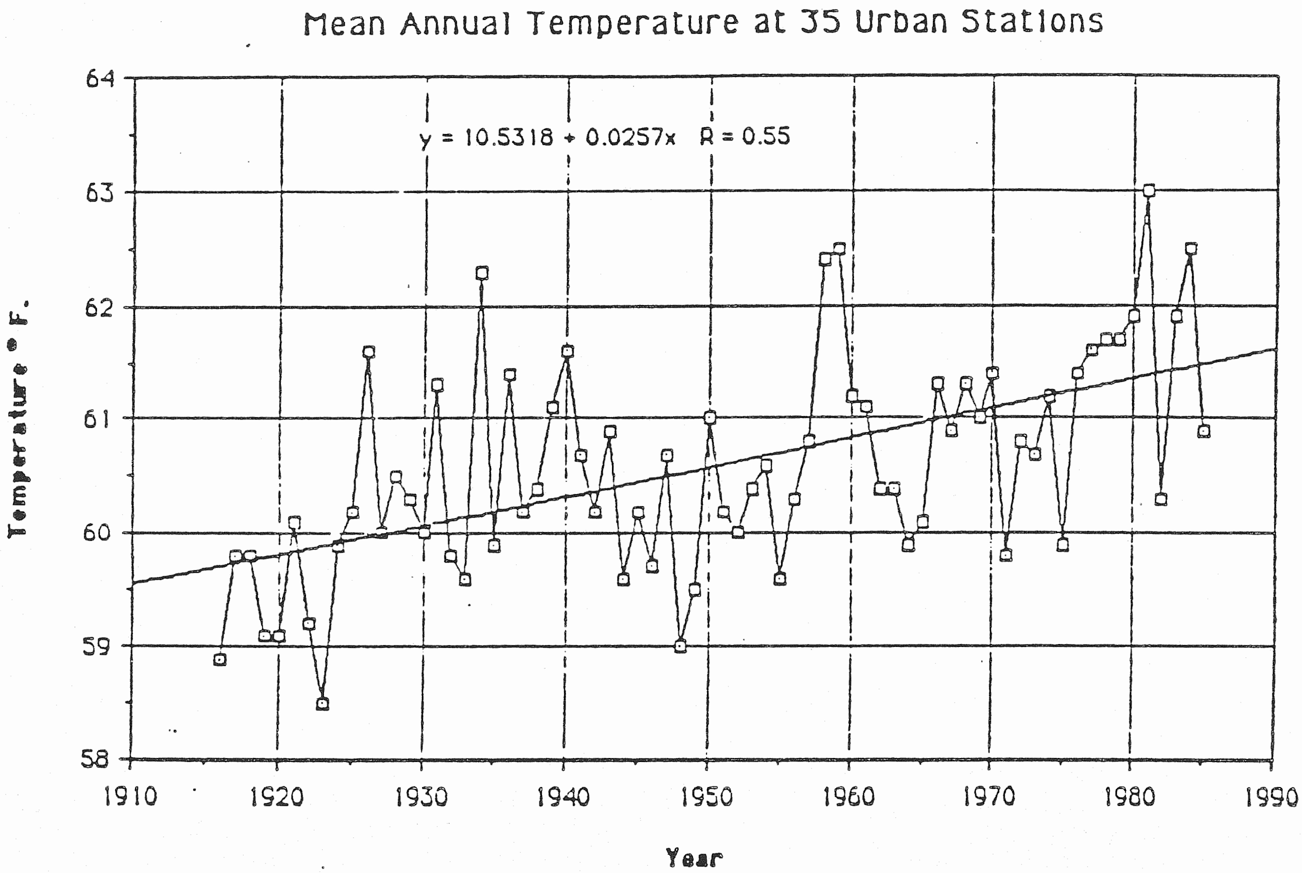


Figure 4

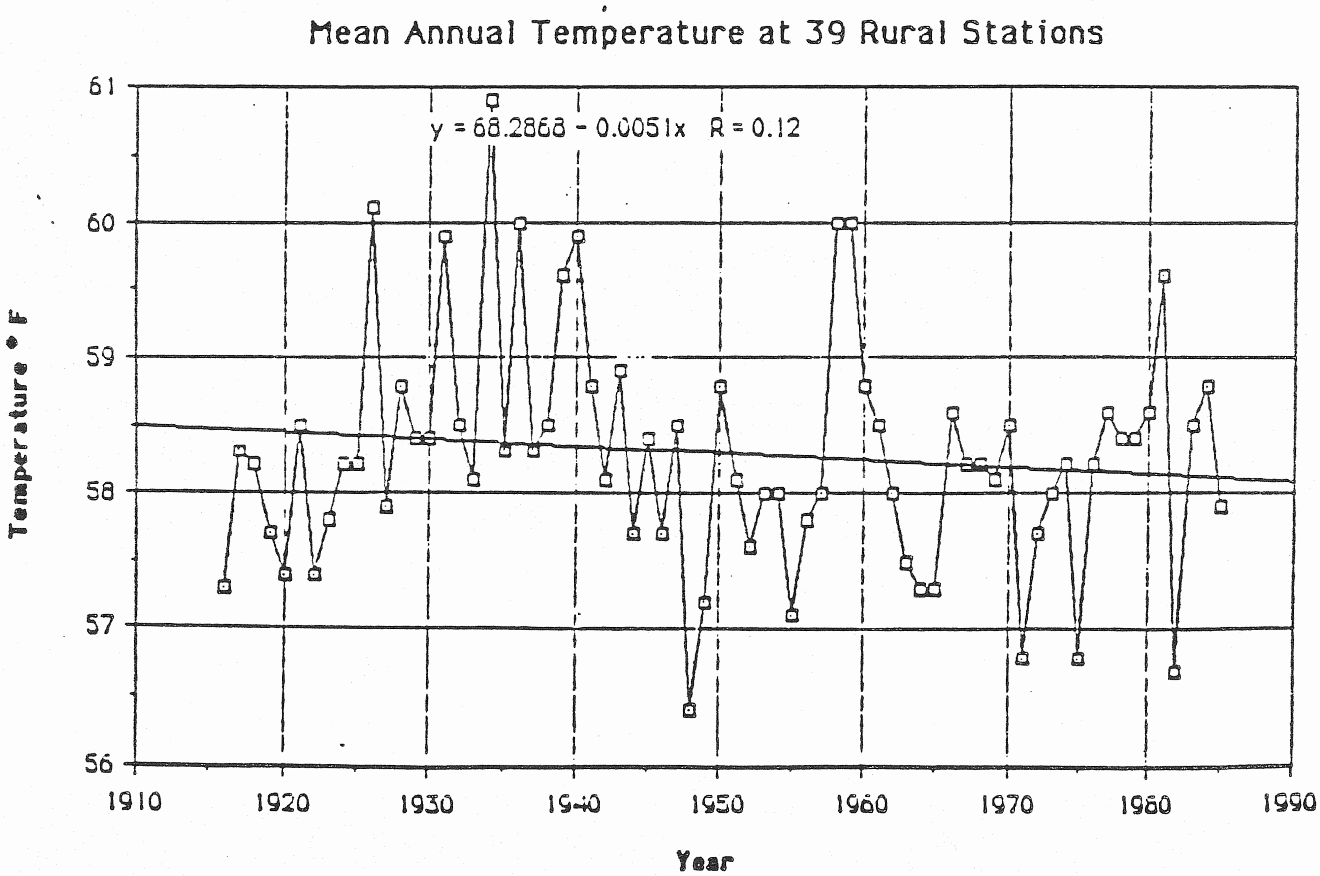


Figure 5

California Countys

Figure 9

California Urban Temperature and Population Trends

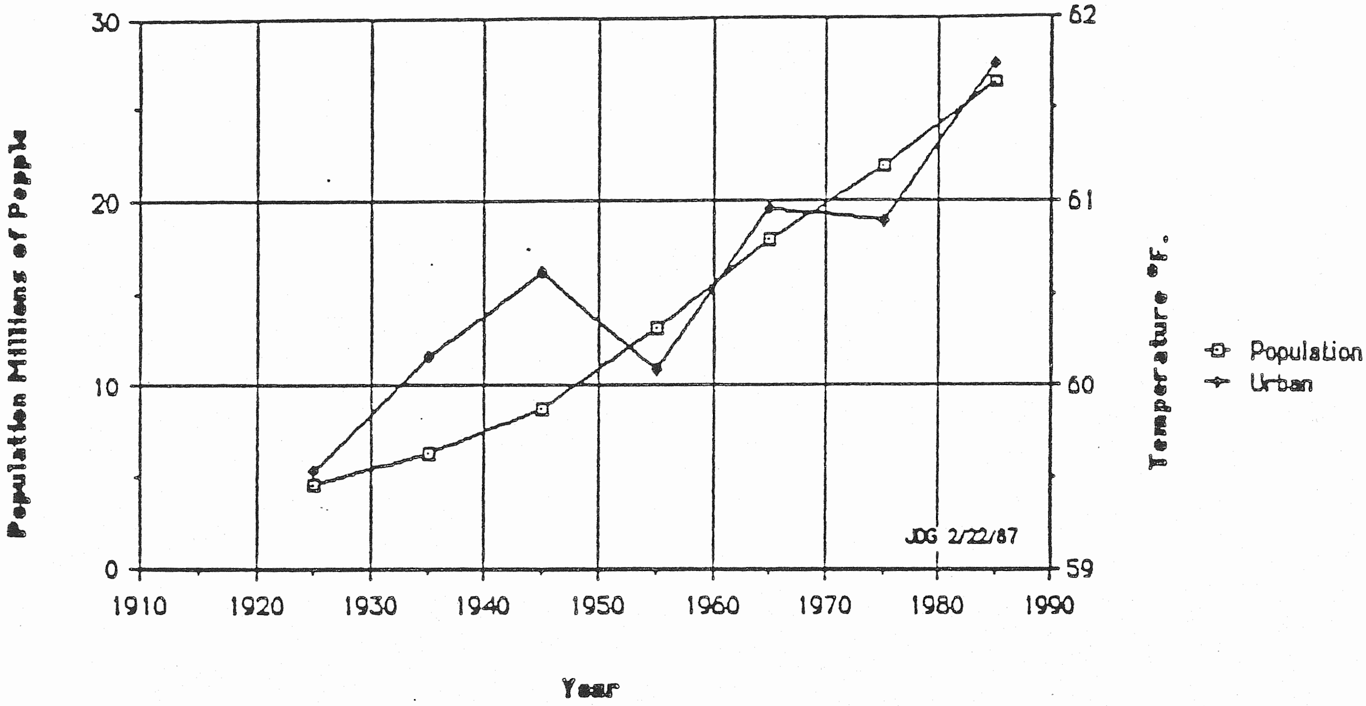


Figure 13

California Rural Temperature and Population Trends

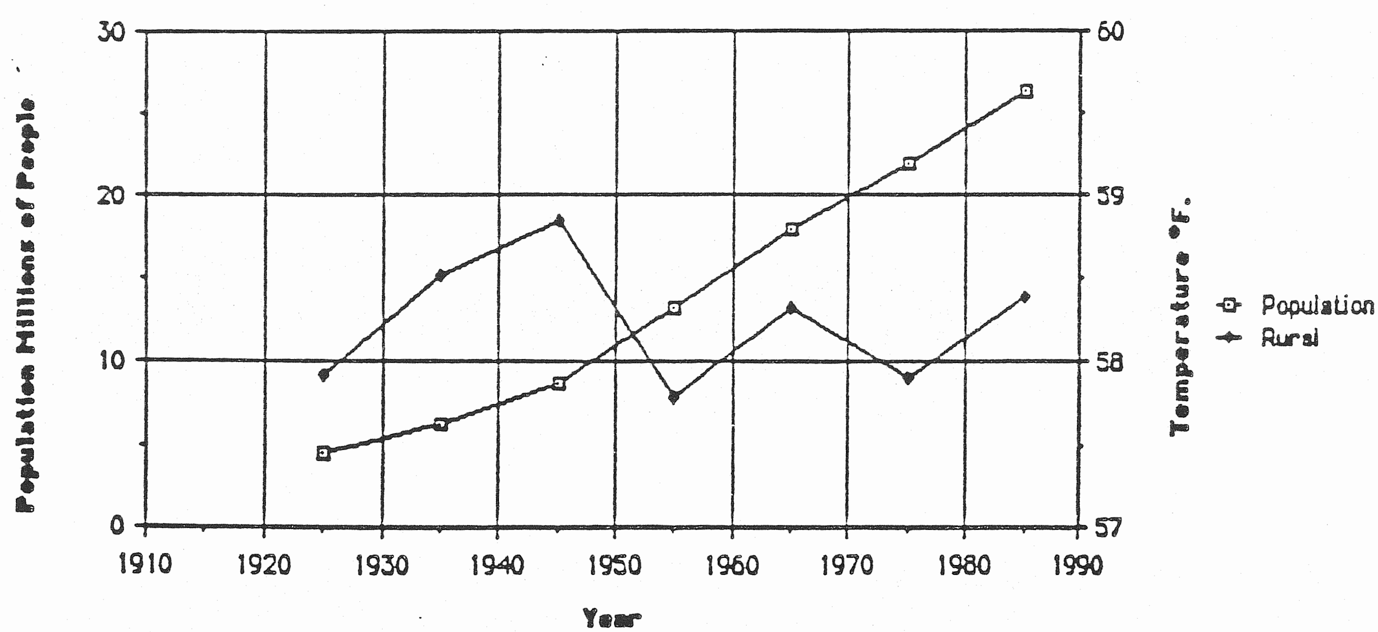


Figure 14

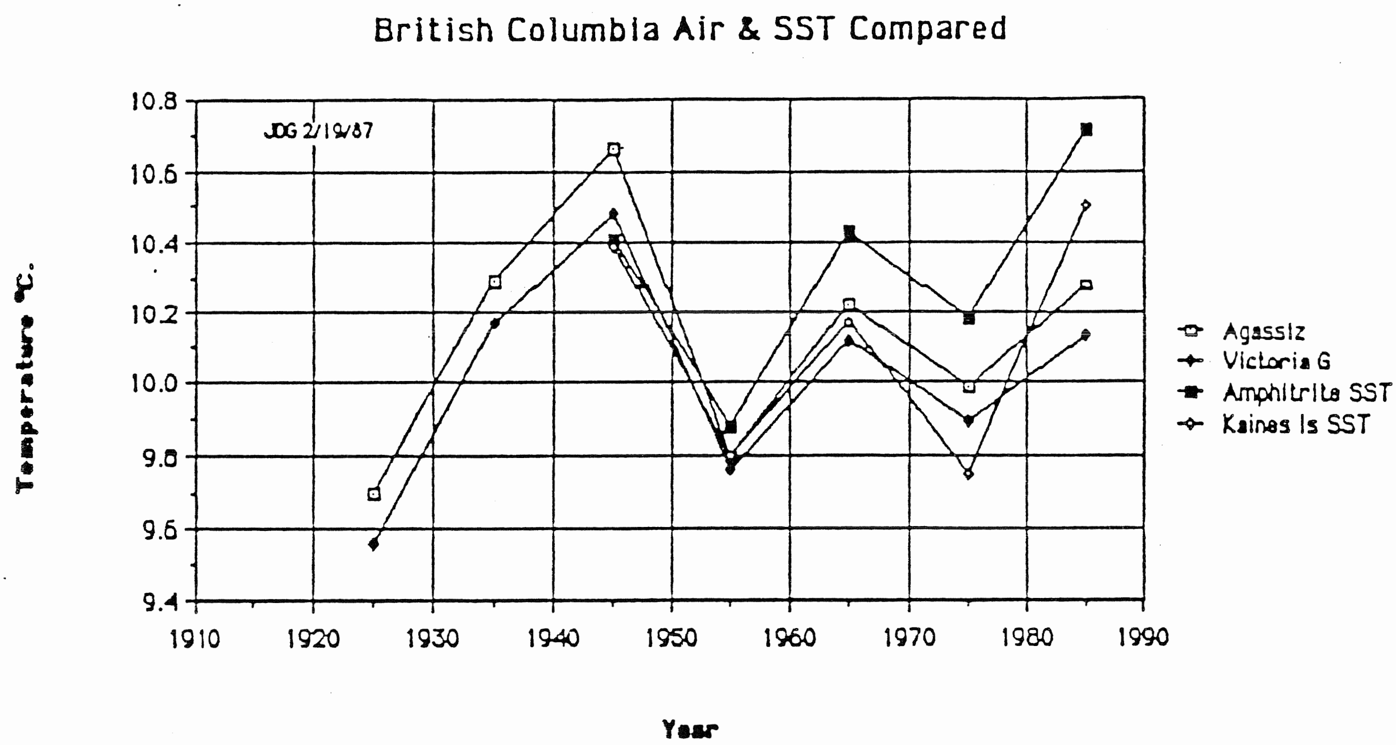


Figure 19

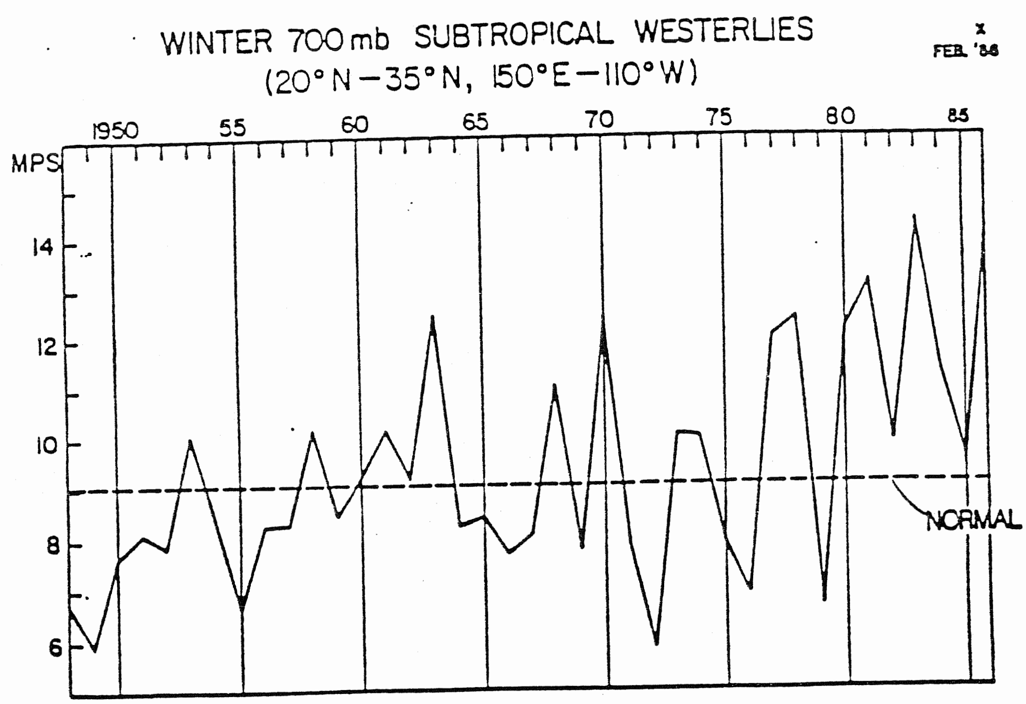


Figure 20

TABLE 1 - MEAN ANNUAL TEMPERATURE AT RURAL LOCATIONS IN CALIFORNIA

Year	Clover-dale	Crescent City	Yreka	Weaver-ville	San Francisco	Liver-more	Santa Cruz	San Luis Obispo	Ojai	Mount Wilson	Elsinore	Cuya-maca	Fort Bidwell	Mc Cloud	Mount Shasta	East Park
County	Sonoma	Del Norte	Siskiyou	Trinity	San Fra.	Alameda	Santa Cruz	San Luis	Ventura	Los Angeles	Riverside	San Diego	Modoc	Shasta	Shasta	Colusa
Rec Beg	1902	1894	1914	1912	1850	1872	1873	1893	1906	1917	1897	1899	1912	1912	1906	1914
dd mm	38 46	41 46	41 43	40 44	37 46	37 40	36 59	35 18	34 27	34 14	33 40	32 59	41 51	41 16	41 19	39 22
ddd mm	122 59	124 12	122 38	122 56	122 26	121 46	122 01	120 40	119 14	118 04	117 20	116 35	120 00	122 08	122 19	122 31
Feet	320'	40'	2625'	2050'	75'	400'	130'	315'	750'	5709'	1255'	4650'	4498'	3300'	3544'	1205'
Division	1	1	1	1	4	4	4	4	6	6	6	6	3	2	2	2
Avg	59.9	53.2	51.7	53.2	57.0	58.9	56.9	59.0	61.4	55.7	63.7	53.1	48.2	49.5	49.4	58.6
Max	62.4	56.3	55.2	57.7	58.9	61.8	59.6	61.8	63.8	59.8	66.9	56.6	52.5	53.2	51.8	60.9
Min	57.1	51.0	47.9	50.2	55.2	56.4	54.8	57.1	59.1	52.3	60.3	47.8	46.0	46.6	43.7	55.6
Sdev	1.048	1.132	1.272	1.303	0.961	1.123	0.966	1.020	1.009	1.531	1.240	1.515	1.242	1.270	1.438	1.003
CV	.018	.021	.025	.025	.017	.019	.017	.017	.016	.027	.019	.028	.026	.026	.029	.017
Range	5.3	5.3	7.3	7.5	3.7	5.4	4.8	4.7	4.7	7.5	6.6	8.8	6.5	6.6	8.1	5.3
Class	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Avg 16-25	58.9	52.7	50.5	53.0	56.6	58.4	56.6	58.7	60.9	55.2	63.9	52.2	48.0	48.8	49.3	58.1
Avg 26-35	59.8	53.6	51.8	53.7	57.2	58.7	57.0	59.1	61.3	56.2	63.5	53.2	48.8	50.0	48.8	58.4
Avg 36-45	60.9	54.2	52.3	53.8	57.3	59.3	57.8	59.2	60.9	56.2	64.0	53.6	48.3	50.1	50.1	59.4
Avg 46-55	59.7	52.2	51.0	52.3	56.0	58.5	56.0	58.5	61.3	54.9	63.0	52.3	48.0	48.3	49.2	58.6
Avg 56-65	60.0	52.9	52.0	53.0	57.1	58.4	56.8	59.4	62.3	55.3	63.3	53.0	48.0	49.3	49.9	58.7
Avg 66-75	59.1	52.6	51.8	52.5	56.5	58.8	56.5	58.3	61.2	55.2	63.4	53.1	48.2	49.2	49.5	58.3
Avg 76-85	60.0	53.4	51.6	53.2	57.8	59.6	57.5	59.9	61.6	56.5	65.2	53.2	47.6	50.2	49.2	58.3
1916	58.4	51.1	49.3	53.0	55.9	58.8	55.3	57.2	59.1	54.0	62.7	52.9	46.2	46.6	50.4	57.7
1917	59.5	52.2	49.0	53.3	56.3	58.8	55.9	59.0	62.1	56.5	62.0	53.2	46.0	48.7	48.9	59.0
1918	59.0	53.0	51.7	55.2	56.8	60.2	56.8	59.5	62.3	55.0	65.0	56.6	48.4	48.8	49.8	58.8
1919	58.3	52.7	51.2	53.7	55.8	57.9	56.0	58.0	60.6	55.4	63.9	53.6	47.2	47.8	49.2	58.6
1920	57.1	52.4	51.4	53.5	56.1	57.7	56.2	57.9	59.9	54.0	63.3	51.3	48.2	49.5	50.9	58.0
1921	59.0	52.9	50.7	54.6	56.9	58.9	57.2	59.1	61.2	55.7	64.6	50.7	49.2	49.9	50.6	58.6
1922	59.3	51.9	48.3	53.2	55.9	57.0	56.1	58.2	60.8	54.6	63.9	52.1	47.3	47.7	48.8	57.0
1923	60.0	53.7	50.6	52.5	57.4	57.7	57.1	59.1	61.4	54.4	64.1	47.8	48.5	48.5	49.3	57.1
1924	58.9	52.7	51.9	50.6	56.9	59.8	57.0	58.8	60.6	56.8	64.8	51.1	48.8	50.2	48.2	57.9
1925	59.0	54.4	50.6	50.2	57.9	57.3	58.4	59.7	60.9	55.4	64.8	52.2	49.9	50.0	47.2	58.0
1926	61.8	55.1	55.2	56.5	58.8	59.4	59.6	60.6	62.4	56.9	65.3	55.0	50.9	52.7	48.8	60.2
1927	60.2	52.8	51.8	54.1	57.2	57.7	57.2	59.1	60.7	55.4	62.6	54.4	47.4	48.4	43.7	57.4
1928	60.5	53.9	52.7	55.1	57.1	58.5	57.3	60.2	62.3	57.7	62.8	55.0	48.8	51.6	44.6	59.4
1929	58.8	53.6	51.7	53.7	57.3	59.0	55.9	59.3	62.5	57.0	63.3	53.0	47.6	50.2	45.2	58.9
1930	60.3	54.0	51.4	53.4	57.9	59.6	56.9	58.9	62.3	57.0	62.6	54.8	47.7	49.8	48.9	58.3
1931	60.8	55.7	53.6	53.5	58.3	61.8	58.3	60.6	63.8	56.1	63.8	56.6	49.4	50.5	51.5	58.7
1932	60.2	53.6	52.3	53.5	57.1	60.1	56.1	58.8	61.1	56.5	60.9	54.3	47.2	49.6	50.6	57.8
1933	59.9	53.1	51.6	52.8	56.3	58.5	55.0	57.4	60.8	56.7	60.3	54.5	47.7	48.7	50.2	58.8
1934	62.4	55.7	54.8	57.7	58.9	60.5	58.0	60.5	62.0	59.8	65.2	55.4	51.9	53.2	51.8	60.4
1935	59.5	52.8	51.4	53.9	57.1	57.1	56.8	57.8	59.2	56.6	62.9	52.6	52.5	50.5	48.3	57.7
1936	62.1	54.8	52.8	55.3	58.4	60.6	58.5	59.9	61.2	57.8	65.0	53.8	48.5	51.9	51.5	60.7
1937	60.2	53.7	49.8	52.4	56.4	59.3	57.0	58.6	59.4	56.7	63.8	53.8	47.8	49.2	48.8	57.2
1938	60.0	53.8	51.7	53.8	56.5	58.4	57.8	58.9	60.1	55.3	64.0	53.0	47.8	50.4	49.8	59.4
1939	61.5	54.4	54.0	54.7	57.5	59.5	57.9	59.2	60.7	58.2	64.4	55.2	49.9	51.1	51.4	60.9
1940	61.4	56.3	53.7	54.7	58.3	60.1	57.9	60.3	61.7	57.2	65.3	56.1	50.0	50.8	51.5	60.4
1941	60.9	55.6	52.8	53.6	58.5	59.4	58.7	59.7	61.3	59.6	63.2	53.4	48.6	49.5	50.2	59.0
1942	60.6	54.1	52.1	52.6	56.5	58.5	56.4	58.6	60.5	55.3	63.9	53.9	47.7	48.7	49.4	58.4
1943	61.7	54.0	52.2	53.0	57.5	59.1	57.6	59.8	62.0	56.7	66.1	53.3	48.4	50.1	50.0	59.5
1944	60.6	52.6	51.6	53.3	56.3	58.6	57.1	58.0	60.3	52.3	62.4	50.7	46.6	49.4	49.0	58.9
1945	60.4	52.7	52.6	54.3	56.7	59.0	56.7	58.7	61.3	53.8	63.3	52.7	47.9	50.0	49.6	59.7
1946	59.4	51.5	51.4	52.0	56.0	57.1	56.4	58.1	60.7	54.5	63.4	53.3	47.7	49.5	48.9	58.1
1947	61.2	53.4	52.0	53.8	57.2	58.7	57.2	59.6	61.5	54.7	63.7	53.1	48.9	50.8	50.2	59.2
1948	59.0	51.0	47.9	50.6	55.8	59.6	55.7	57.9	60.7	53.4	62.1	51.2	48.3	48.6	47.5	57.0
1949	59.5	51.9	50.7	52.0	55.4	58.0	55.3	58.2	60.8	53.5	62.2	50.7	47.3	47.9	48.9	58.4
1950	60.0	52.6	51.7	52.8	56.3	60.0	56.2	59.5	61.8	57.1	63.9	53.1	49.4	48.7	50.3	60.1
1951	59.6	52.3	52.0	53.6	55.3	58.7	55.9	58.7	61.1	54.8	62.9	51.9	48.4	48.1	50.0	59.5
1952	59.4	51.9	51.5	52.7	55.5	58.9	55.9	57.5	60.9	53.7	62.4	52.0	47.6	48.4	49.6	58.6
1953	60.5	53.2	51.3	52.6	56.8	58.3	55.9	59.2	62.1	53.3	63.3	52.7	48.6	48.0	49.7	59.0
1954	59.5	53.1	51.2	52.2	56.3	57.8	56.3	58.8	62.4	57.1	63.7	53.8	48.6	48.1	49.1	58.4
1955	59.2	51.2	50.5	50.6	55.2	57.5	54.8	57.5	60.9	54.4	62.1	51.6	46.8	47.2	48.2	57.5
1956	59.9	52.5	51.3	51.7	56.5	58.1	55.7	58.8	61.4	56.0	62.9	52.6	47.7	49.2	49.0	58.4
1957	59.7	53.1	50.8	52.9	57.3	59.1	57.2	59.3	62.3	54.3	64.3	52.7	47.2	48.4	46.4	58.1
1958	61.4	54.9	53.9	55.1	58.8	61.6	58.5	61.5	63.5	56.4	64.5	54.4	50.3	51.1	51.3	60.2
1959	62.3	53.0	52.5	53.5	58.7	60.1	58.0	61.8	63.8	57.6	65.3	54.6	49.0	50.2	51.1	60.4
1960	59.9	52.5	53.2	53.2	56.4	58.6	56.5	59.1	62.9	56.6	63.6	53.5	48.1	49.2	50.6	59.5
1961	60.5	52.8	52.5	53.1	57.0	58.0	57.0	60.0	62.7	56.0	63.6	53.3	48.2	48.8	50.3	59.1
1962	59.8	52.2	51.3	53.2	56.1	57.4	55.8	58.3	61.6	53.3	62.0	52.8	47.1	49.4	50.0	58.5
1963	58.2	53.2	51.6	52.5	57.1	56.4	56.7	58.7	61.8	53.9	62.5	52.9	48.1	49.2	49.6	57.4
1964	59.1	52.1	51.1	52.1	56.5	57.0	56.1	57.8	61.5	53.2	62.2	51.7	46.8	48.2	48.5	57.8
1965	58.7	52.8	51.8	52.6	56.5	57.3	56.8	58.2	61.2	53.5	62.5	51.8	47.8	49.1	48.7	57.7
1966	59.5	52.9	52.5	53.0	56.8	58.6	56.9	58.8	62.4	54.9	64.1	54.2	48.9	49.5	50.4	59.2
1967	59.4	53.0	51.7	52.6	57.0	58.4	56.8	59.1	62.5	54.0	63.7	52.9	48.5	49.6	49.8	58.9
1968	59.6	52.9	51.5	52.7	57.0	59.0	56.9	59.1	61.8	55.4	64.0	53.4	48.7	49.8	48.4	58.4
1969	59.2	52.9	51.9	52.4	56.5	59.6	56.6	58.7	60.4	54.8	63.9	54.6	48.5	49.8	49.6	58.4
1970	59.8	53.3	52.7	53.4	57.0	59.8	57.0	58.2	61.0	55.8	64.2	53.5	48.2	49.9	50.0	59.0
1971	58.7	51.2	50.7	51.2	55.6	58.0	55.6	57.1	60.5	54.7	62.5	51.6	46.8	47.9	48.3	57.3
1972	58.4	52.5	51.7	52.3	56.1	58.6	57.2	58.7	61.9	56.0	63.7	53.5	47.4	49.8	49.2	57.8
1973	59.5	52.8	53.0	53.5	56.4	59.1	56.5	58.3	60.9	55.6	61.9	51.8	49.0	49.3	50.0	58.6
1974	59.1	52.6	52.0	53.0	56.3	59.0	56.0	57.7	61.0	56.0	63.2	53.4	48.7	49.4	49.8	58.0
1975	58.1	52.0	50.3	51.3	55.8	58.1	55.6	57.3	59.8	55.0	62.8	51.9	47.4	48.4	48.3	57.4
1976	59.6	52.6	51.1	53.4	57.8	58.3	57.7	60.2	62.3	55.7	65.2	52.6	48.0	50.7	48.7	58.8
1977	59.4	52.8	51.8	53.1	57.0	59.7	57.4	60.1	62.7	57.1	65.8	53.7	47.0	50.7	48.1	58.4
1978	60.3	53.5	51.7	53.3	58.1	60.3	57.1	59.5	62.2	58.1	64.6	53.4	47.4	50.2	48.5	58.4
1979	59.7	54.4	52.5	52.4	58.1	59.5	57.3	59.6	61.1	56.3	64.7	52.9	47.6	50.0	48.1	57.9
1980	60.6	53.6	52.4	52.5	57.4	59.7	57.7	60.2	61.3	58.8	65.8	54.3	48.8	50.7	49.0	58.3
1981	61.2	54.3	52.7	55.0	57.3	61.6	57.6	60.5	61.9	58.1	66.9	55.2	48.8	51.6	50.9	60.1
1982	59.0	53.0	50.1	51.2	56.2	57.8	56.6	58.5	59.9	53.3	63.7	50.2	46.4	48.1	47.6	55.6
1983	60.3	55.2	51.3	54.0	58.9	59.7	58.6	60.4	61.4	54.8	64.9	53.1	47.8	49.4	48.1	58.8
1984	60.8	53.1	51.2	53.8	58.3	58.9	58.1	60.5	62.8	57.5	66.4	53.9	48.8	50.0	48.6	58.9
1985	59.3	51.9	51.3	53.6	58.6	59.3	57.1	59.1	60.4	57.1	64.1	52.6	48.2	50.3	48.8	58.0
Year	Clover-dale	Crescent City	Yreka	Weaver-ville	San Francisco	Liver-more	Santa Cruz	San Luis Obispo	Ojai	Mount Wilson	Elsinore	Cuya-maca	Fort Bidwell	Mc Cloud	Mount Shasta	East Park

TABLE 1(Con) - MEAN ANNUAL TEMPERATURE AT RURAL LOCATIONS IN CALIFORNIA

Year	Lemon Cove	Glen-ville	Tejon Ranch	Lindsay	Visalia	Mariposa	Indio	Average	10 Yr Avg	CV-Year	CV Running	Maximum	Minimum
County	Tulare	Kern	Kern	Tulare	Tulare	Mariposa	Riverside						
Rec Beg	1899	1912	1899	1914	1888	1912	1878						
dd.mm	36.23	35.44	35.02	36.11	36.20	35.05	33.44						
ddd.mm	119.02	118.40	118.45	119.04	119.18	119.23	116.15						
feet	513	3500	1425	395	354	675	11						
Division	5	5	5	5	5	5	7						
Avg	63.1	54.5	63.9	62.3	63.4	65.4	73.1						
Max	65.8	58.6	67.9	64.3	66.5	68.4	76.5						
Min	60.0	51.0	61.0	60.2	61.1	62.8	71.0						
Stdev	1.242	1.276	1.496	0.912	1.140	1.281	0.902						
CV	.020	.023	.023	.015	.018	.020	.013						
Range	5.8	7.6	6.9	4.1	5.4	5.6	5.5						
Class	R	R	R	R	R	R	R						
Avg 16-25	62.3	54.0	64.2	62.0	62.4	65.0	72.9	57.9				72.9	48.0
Avg 26-35	62.6	55.2	65.3	62.5	63.6	65.5	73.2	58.5				73.2	47.5
Avg 36-45	64.2	55.2	64.2	63.1	64.3	66.4	72.9	58.8				72.9	48.3
Avg 46-55	63.2	53.3	62.5	61.5	63.7	65.7	72.6	57.8				72.6	46.8
Avg 56-65	63.2	54.3	63.7	62.1	63.4	65.7	73.5	58.3				73.5	48.0
Avg 66-75	62.4	54.2	63.2	62.2	62.7	64.4	73.2	57.9				73.2	47.2
Avg 76-85	63.1	55.0	63.6	62.3	63.2	64.3	73.3	58.4				73.3	47.6
1916	64.4	53.8	61.0	61.4	62.4	65.0	72.4	57.3		.093		72.4	46.2
1917	62.5	54.8	65.1	62.1	62.9	67.5	72.9	58.3		.095		72.9	46.0
1918	62.6	51.0	63.9	61.8	61.1	65.2	72.6	58.2		.086		72.6	48.4
1919	62.1	54.9	65.1	61.3	62.6	63.1	72.9	57.7		.089		72.9	47.2
1920	62.0	53.9	64.1	60.9	61.7	64.2	71.6	57.4		.087		71.6	48.2
1921	63.1	55.3	65.0	62.9	63.2	66.4	73.5	58.5		.090		73.5	48.1
1922	62.7	53.5	63.4	62.0	61.8	64.4	73.0	57.4		.097		73.0	46.6
1923	61.6	53.1	64.1	61.8	61.8	64.1	73.0	57.8		.097		73.0	46.2
1924	61.4	55.1	65.4	62.7	63.2	64.4	73.8	58.2		.096		73.8	47.4
1925	60.9	55.0	64.7	62.8	63.0	65.2	73.0	58.2	57.9	.093	.0077	73.0	47.0
1926	62.7	57.0	67.9	64.2	65.6	65.7	73.9	60.1	58.2	.086	.0134	73.9	48.0
1927	60.0	54.8	64.3	61.9	63.3	65.3	72.4	57.9	58.1	.097	.0135	72.4	43.7
1928	61.7	55.2	66.0	62.9	63.9	66.1	73.3	58.8	58.2	.094	.0139	73.3	44.6
1929	62.0	55.0	65.0	62.1	63.9	65.8	73.3	58.4	58.3	.097	.0137	73.3	45.2
1930	63.7	54.3	65.6	62.3	63.7	66.1	73.1	58.4	58.4	.096	.0127	73.1	43.7
1931	65.8	56.6	67.0	64.1	65.8	68.0	73.2	59.9	58.5	.094	.0151	73.2	44.8
1932	64.2	54.5	64.9	62.4	63.9	66.3	72.0	58.5	58.6	.092	.0135	72.0	46.2
1933	62.6	55.6	64.9	61.9	63.7	65.2	72.7	58.1	58.7	.090	.0129	72.7	47.7
1934	64.9	58.6	67.8	64.3	66.5	68.0	76.5	60.9	58.9	.083	.0173	76.5	50.9
1935	63.6	55.4	64.2	62.3	63.4	65.2	72.7	58.3	58.8	.086	.0172	72.7	47.7
1936	65.2	56.9	66.8	64.1	65.7	68.3	73.8	60.0	58.9	.089	.0170	73.8	48.5
1937	64.1	55.4	64.9	63.0	64.4	65.9	73.8	58.3	59.0	.096	.0163	73.8	47.5
1938	63.5	55.4	65.0	63.1	64.3	65.3	72.5	58.5	58.9	.089	.0165	72.5	47.8
1939	65.4	56.3	63.8	63.8	65.3	65.8	73.4	59.6	59.1	.083	.0165	73.4	49.6
1940	65.6	56.7	64.1	64.0	65.5	67.5	74.2	59.9	59.2	.085	.0166	74.2	49.6
1941	64.2	54.0	63.8	63.2	64.0	65.8	71.8	58.8	59.1	.088	.0162	71.8	47.3
1942	63.1	54.0	63.1	62.6	63.5	65.4	73.2	58.1	59.1	.091	.0168	73.2	47.4
1943	64.2	56.8	63.9	62.8	64.0	66.8	73.3	58.9	59.1	.089	.0159	73.3	48.4
1944	63.2	53.5	63.2	61.8	63.0	66.0	71.0	57.7	58.8	.092	.0135	71.0	46.6
1945	63.8	53.8	62.9	62.8	63.7	67.0	71.7	58.4	58.8	.090	.0133	71.7	47.9
1946	62.4	54.7	63.7	61.3	63.0	66.1	72.5	57.7	58.6	.091	.0125	72.5	47.2
1947	63.2	54.8	62.0	61.2	63.3	65.7	73.4	58.5	58.6	.087	.0123	73.4	48.2
1948	61.8	52.0	61.2	60.2	62.3	65.2	71.5	56.4	58.4	.100	.0174	71.5	45.2
1949	62.3	51.2	61.0	61.0	63.3	66.6	71.6	57.2	58.2	.085	.0168	71.6	45.9
1950	65.0	53.1	64.3	63.5	65.5	67.8	73.5	58.8	58.1	.096	.0140	73.5	47.1
1951	64.0	53.9	62.3	62.1	64.4	66.1	72.1	58.1	58.0	.091	.0133	72.1	47.3
1952	64.3	53.1	62.2	62.2	64.5	65.5	73.0	57.8	58.0	.096	.0134	73.0	46.1
1953	63.3	53.6	62.2	61.2	63.0	64.8	73.1	58.0	57.9	.091	.0121	73.1	47.2
1954	63.2	53.8	63.2	61.4	62.7	65.4	73.9	58.0	57.9	.091	.0121	73.9	47.9
1955	62.4	52.9	63.0	60.8	63.2	65.4	71.7	57.1	57.8	.097	.0124	71.7	45.9
1956	62.5	53.6	63.0	61.3	63.1	65.3	72.8	57.8	57.8	.092	.0124	72.8	45.9
1957	63.4	53.5	62.9	62.1	63.2	65.5	73.7	58.0	57.7	.097	.0116	73.7	46.5
1958	65.1	55.2	65.2	63.9	65.3	67.2	75.3	60.0	58.1	.089	.0144	75.3	49.0
1959	65.4	55.1	66.3	63.3	65.0	68.4	74.9	60.0	58.3	.083	.0166	74.9	49.0
1960	64.4	55.1	64.6	62.4	64.1	66.3	74.5	58.8	58.3	.083	.0166	74.5	48.1
1961	63.8	54.3	63.8	62.1	64.0	65.7	73.8	58.5	58.4	.090	.0166	73.8	48.2
1962	63.0	54.2	64.0	61.9	63.2	65.7	74.0	58.0	58.4	.092	.0163	74.0	47.1
1963	61.6	55.4	62.5	61.7	62.6	64.4	73.0	57.5	58.4	.087	.0169	73.0	47.8
1964	61.9	52.9	63.0	61.5	62.1	64.8	71.2	57.3	58.3	.092	.0179	71.2	46.8
1965	61.3	53.9	61.6	61.2	61.3	63.5	71.8	57.3	58.3	.086	.0174	71.8	47.8
1966	63.1	55.5	64.6	62.7	63.3	65.6	73.5	58.6	58.4	.089	.0171	73.5	48.1
1967	62.6	54.6	64.2	62.0	62.8	65.1	72.8	58.2	58.4	.091	.0170	72.8	47.2
1968	62.5	54.1	63.5	62.8	63.0	65.0	73.6	58.2	58.2	.092	.0141	73.6	47.2
1969	62.8	54.9	63.5	62.7	62.5	64.5	74.3	58.1	58.0	.091	.0093	74.3	47.8
1970	63.6	55.1	63.9	62.7	63.3	65.4	73.0	58.5	58.0	.090	.0087	73.0	47.4
1971	61.1	52.6	62.1	60.8	61.6	62.9	72.3	56.8	57.8	.094	.0104	72.3	45.4
1972	61.7	53.5	63.1	61.6	62.5	63.4	73.5	57.7	57.8	.091	.0104	73.5	46.6
1973	62.8	53.8	61.4	62.3	63.2	64.4	73.2	58.0	57.9	.089	.0102	73.2	46.3
1974	63.0	54.5	63.7	62.6	63.2	64.8	73.7	58.2	58.0	.088	.0096	73.7	48.7
1975	60.8	53.6	61.6	61.8	61.6	63.0	72.1	56.8	57.9	.089	.0109	72.1	47.4
1976	62.4	54.5	62.9	62.2	62.5	63.7	72.9	58.2	57.9	.086	.0103	72.9	48.8
1977	63.1	55.3	62.6	63.0	63.0	63.6	73.6	58.6	57.9	.089	.0109	73.6	47.8
1978	63.6	55.1	62.0	62.4	63.1	64.0	73.2	58.4	57.9	.090	.0110	73.2	47.4
1979	63.6	54.6	64.3	62.8	63.6	65.0	73.1	58.4	58.0	.092	.0114	73.1	47.5
1980	63.4	55.2	63.8	62.9	63.2	65.0	73.8	58.6	58.0	.088	.0114	73.8	48.8
1981	63.9	55.7	65.4	62.8	64.6	66.1	75.2	59.6	58.3	.087	.0120	75.2	49.0
1982	61.9	53.9	63.0	61.6	62.1	62.8	71.8	56.7	58.1	.096	.0146	71.8	46.2
1983	63.5	54.9	63.8	62.2	63.7	63.9	72.6	58.5	58.2	.093	.0146	72.6	47.1
1984	63.9	55.6	64.8	62.5	64.1	65.2	73.6	58.8	58.3	.094	.0150	73.6	46.8
1985	62.3	54.7	63.0	60.7	62.5	64.1	73.4	57.9	58.4	.089	.0128	73.4	48.2
Year	Lemon Cove	Glen-ville	Tejon Ranch	Lindsay	Visalia	Mariposa	Indio	Average	10 Yr Avg	CV-Year	CV Running	Maximum	Minimum

TABLE 1(Con) - MEAN ANNUAL TEMPERATURE AT URBAN LOCATIONS IN CALIFORNIA

Year	Bakersfield	Berkeley	Oakland	Mount Hamilton	Los Gatos	San Jose	Salinas	Paso Robles	Santa Maria	Los Angeles	Claremont PC	San Bernardino	Redlands	Riverside
County	Kern	Alameda	Alameda	Santa Clara	Santa Clara	Santa Clara	Monterey	San Luis	Santa Barbara	Los Angeles	Los Angeles	San Brdo	Riverside	Riverside
Rec Beg	1890	1888	1877	1890	1888	1873	1873	1879	1887	1877	1902	1871	1893	1882
dd.mm	35.25	37.52	37.44	37.20	37.14	37.21	36.40	35.38	34.54	34.03	34.06	34.08	34.03	33.57
ddd.mm	119.30	122.15	122.12	121.39	121.58	121.54	121.36	120.41	120.27	118.14	117.43	117.16	117.11	117.23
Feet	495'	345'	8'	4206'	365'	87	68'	700'	254	257	1201'	1125'	1318'	840'
Division	5	4	4	4	4	4	4	4	6	6	6	6	6	6
Avg	65.0	57.0	57.2	53.8	58.8	59.1	57.0	58.9	57.1	64.7	62.3	64.2	63.3	63.7
Max	67.8	59.3	61.4	57.1	62.3	61.7	60.6	61.2	60.1	68.9	65.0	68.1	66.6	66.9
Min	61.9	54.9	54.6	50.8	56.3	56.7	54.4	57.1	54.0	60.9	60.2	61.3	60.8	60.9
Stdev	1.345	0.992	1.167	1.370	1.103	1.131	1.088	0.904	1.215	1.617	1.011	1.434	1.327	1.319
CV	.021	.016	.021	.025	.019	.019	.019	.015	.021	.025	.016	.022	.021	.021
Range	5.9	4.4	6.8	6.3	5.8	5.0	6.2	4.1	6.1	8.0	4.8	6.8	5.8	6.0
Class	U	U	U	U	U	U	U	U	U	U	U	U	U	U
Avg 16-25	63.5	56.4	56.1	52.9	58.0	57.4	55.7	58.2	56.2	62.9	61.5	62.9	62.4	63.3
Avg 26-35	64.3	56.6	56.5	53.8	58.5	58.1	56.3	58.6	57.1	63.9	62.2	63.5	62.7	63.1
Avg 36-45	65.0	57.2	57.1	53.5	58.8	59.5	57.2	59.0	57.9	64.1	62.1	63.5	62.4	63.7
Avg 46-55	64.5	56.9	56.5	52.7	58.1	59.0	57.0	58.6	56.5	63.8	62.0	63.7	62.2	62.1
Avg 56-65	64.7	57.1	57.7	53.9	59.5	60.0	57.6	59.2	56.9	65.2	62.8	64.6	64.6	64.0
Avg 66-75	66.1	57.0	57.3	54.3	58.9	59.4	57.0	58.7	56.6	65.5	62.2	64.7	63.5	64.2
Avg 76-85	66.3	57.5	58.8	54.6	59.3	59.8	57.8	59.9	58.2	66.9	62.9	66.4	64.6	65.3
1916	62.9	55.9	53.6	52.6	57.6	56.9	53.7	57.9	56.2	60.9	60.3	62.0	62.0	62.3
1917	64.0	56.3	56.9	54.2	58.8	57.8	56.0	58.7	57.4	62.8	60.9	62.9	63.2	64.2
1918	63.8	57.1	56.5	52.7	58.2	57.6	56.6	59.5	55.1	63.9	61.2	63.7	63.3	63.5
1919	61.9	56.2	55.6	52.2	57.3	56.7	55.1	57.6	54.0	62.9	61.6	62.4	62.4	62.6
1920	62.7	56.2	55.5	50.9	57.2	57.0	55.3	57.8	54.9	62.4	61.3	62.0	61.4	62.4
1921	64.1	57.2	56.4	53.0	58.4	57.7	56.4	58.9	56.1	63.0	61.8	63.3	62.3	63.7
1922	63.1	56.8	54.6	52.7	57.2	56.8	55.1	57.7	56.5	62.5	61.3	62.5	61.5	63.1
1923	62.7	57.1	56.3	52.3	56.8	57.4	54.4	57.9	57.3	63.7	61.5	62.9	62.4	63.4
1924	64.5	54.9	56.5	54.6	58.4	57.8	56.5	58.2	56.7	63.5	62.8	63.2	62.4	63.7
1925	64.8	56.3	57.0	53.6	58.4	58.5	56.3	58.4	58.2	63.8	62.4	63.8	63.2	64.1
1926	66.2	58.1	58.3	56.2	59.9	59.8	57.8	60.2	59.4	66.1	63.5	66.4	64.4	66.4
1927	63.8	56.6	56.4	52.6	58.2	58.1	57.0	58.9	57.6	63.3	63.1	64.1	63.3	63.2
1928	64.9	56.1	56.5	54.9	59.8	58.3	56.8	59.6	57.7	64.2	62.4	64.6	63.8	63.0
1929	64.0	56.8	56.6	55.6	59.2	58.0	56.5	59.0	57.5	64.6	62.4	65.1	64.0	62.7
1930	64.4	57.0	56.8	52.6	58.7	58.1	56.7	58.8	57.3	64.9	61.8	64.7	62.6	62.5
1931	66.3	57.8	57.3	54.2	59.5	59.5	56.6	60.3	58.0	66.5	63.8	66.0	63.4	63.6
1932	64.3	56.3	56.3	54.3	58.2	58.3	55.4	58.1	56.7	63.6	60.8	61.3	61.1	61.7
1933	64.8	55.6	55.5	55.0	57.0	57.6	55.8	57.6	56.0	62.4	61.2	61.5	61.4	61.7
1934	66.6	58.2	58.3	57.1	60.3	60.1	59.2	60.9	59.5	66.8	64.2	64.0	64.4	64.4
1935	64.1	56.0	56.1	53.6	58.3	58.1	56.4	57.1	57.0	63.6	61.8	62.0	62.0	61.9
1936	65.5	57.8	57.9	56.6	59.8	60.2	57.6	59.1	58.6	65.2	63.5	64.6	63.4	64.7
1937	64.0	56.2	56.8	53.1	58.4	58.8	57.2	58.1	57.0	63.5	62.9	63.2	62.3	63.3
1938	65.0	56.5	56.9	53.8	57.9	58.6	57.5	58.2	58.0	64.6	62.7	63.5	62.3	64.0
1939	65.4	57.3	57.0	54.8	58.9	59.2	56.8	59.0	57.7	65.4	63.5	64.2	62.7	64.6
1940	66.4	57.8	58.2	54.0	59.5	60.6	58.3	60.4	58.9	64.9	62.7	64.3	63.0	65.0
1941	64.8	58.2	58.4	52.0	59.5	60.4	57.9	59.2	59.5	64.0	61.0	63.0	61.8	63.1
1942	64.2	56.6	56.4	52.4	58.2	58.9	56.2	59.0	57.8	63.5	61.3	63.2	62.6	63.4
1943	64.8	58.0	57.0	53.3	59.3	59.9	57.0	59.7	57.9	64.2	62.3	64.2	63.5	64.3
1944	64.6	56.3	56.1	52.3	58.0	59.1	56.3	58.5	56.8	62.2	60.2	62.1	60.8	62.0
1945	65.3	56.8	56.3	52.9	58.8	59.4	57.1	58.7	57.1	63.1	61.5	63.0	61.8	62.5
1946	64.2	56.2	55.2	52.3	57.0	58.5	56.6	58.1	56.2	63.2	62.0	63.7	62.9	63.2
1947	64.7	58.3	57.2	53.7	58.1	59.6	58.2	59.4	57.1	64.0	63.1	64.4	63.1	63.4
1948	63.8	56.4	55.5	50.8	56.8	58.3	56.6	57.6	55.9	63.0	60.8	62.4	61.0	61.1
1949	64.3	56.6	56.2	52.8	57.0	58.4	56.3	57.5	55.8	63.3	61.0	62.6	61.8	60.8
1950	66.2	57.4	57.3	55.4	59.0	60.2	57.7	59.8	57.4	63.8	62.6	64.3	63.3	61.4
1951	65.2	56.3	56.7	53.8	57.9	59.2	56.7	58.7	56.7	63.6	61.9	63.2	62.0	61.6
1952	64.6	56.2	56.9	51.8	58.2	59.3	56.9	59.3	56.2	63.6	61.7	63.3	61.8	61.5
1953	63.8	57.9	57.3	51.6	58.3	59.5	57.6	59.0	57.1	64.6	62.3	64.3	61.7	61.4
1954	64.4	57.7	57.1	53.4	59.6	59.1	57.8	58.9	57.1	64.9	62.5	64.9	62.1	63.3
1955	64.2	55.9	55.1	51.4	58.9	58.2	55.9	58.0	55.0	63.7	62.0	63.6	62.4	62.9
1956	64.5	56.9	56.1	53.1	59.6	59.2	57.5	58.3	56.0	64.8	61.9	64.5	63.1	63.5
1957	64.8	57.8	58.1	52.7	59.8	60.2	58.7	59.3	57.2	65.7	62.5	64.8	64.0	63.9
1958	66.1	59.1	59.5	54.2	62.2	61.7	59.5	60.6	58.7	67.1	63.7	66.3	65.8	64.8
1959	66.4	59.3	59.2	56.0	62.3	61.4	58.5	60.5	58.5	67.3	64.6	66.3	66.5	66.3
1960	65.4	56.1	57.5	54.7	60.2	60.4	56.7	59.4	56.4	65.7	63.4	64.7	65.3	64.9
1961	64.5	56.9	57.6	55.1	60.3	60.2	57.6	59.8	57.1	65.3	63.1	64.6	65.2	64.6
1962	63.8	56.2	57.1	54.4	57.9	59.5	56.7	59.0	55.9	63.2	62.0	63.3	64.4	63.2
1963	63.4	56.8	57.2	53.3	56.5	59.6	57.2	58.7	57.0	65.1	62.7	64.0	64.4	63.7
1964	64.4	56.3	56.9	52.4	57.9	58.8	56.2	58.0	55.0	63.6	61.7	63.4	63.5	62.8
1965	63.8	53.7	57.4	53.4	58.0	58.8	57.0	58.2	56.9	64.3	62.5	63.6	63.6	63.2
1966	65.2	56.6	58.5	55.1	58.9	59.9	57.4	58.9	56.9	66.0	63.4	65.1	64.9	64.8
1967	65.1	56.9	57.7	54.8	59.0	59.5	57.3	59.2	56.8	66.5	62.9	64.7	64.3	65.1
1968	66.3	57.0	58.1	55.2	59.2	59.8	57.3	58.9	58.3	66.2	63.4	64.9	64.5	64.8
1969	66.6	57.2	57.2	54.2	59.2	59.0	56.7	58.1	57.2	65.4	62.2	64.3	63.7	64.1
1970	67.4	58.3	57.7	55.1	59.7	60.3	57.6	59.3	56.7	66.1	62.5	64.8	63.7	64.3
1971	64.7	56.3	56.1	53.0	58.0	58.5	56.4	57.9	54.6	65.1	61.4	64.5	62.8	63.3
1972	65.1	56.9	57.4	54.3	59.0	59.5	57.6	58.6	56.8	66.5	62.1	64.8	63.8	64.3
1973	66.9	57.5	57.0	53.7	59.1	59.7	56.7	58.3	56.4	65.0	61.1	64.4	61.9	63.2
1974	67.5	56.8	57.1	54.2	58.6	59.2	56.6	59.1	56.4	65.3	61.9	65.5	63.4	64.8
1975	65.9	56.0	56.6	53.5	57.8	58.2	56.0	57.9	55.5	63.0	60.9	64.2	62.5	63.4
1976	67.0	58.3	57.7	55.4	58.9	59.3	57.4	59.2	58.0	66.2	63.0	66.0	63.9	63.8
1977	67.8	56.9	58.7	55.2	58.9	59.8	58.6	59.6	57.9	66.9	62.5	66.5	65.1	65.3
1978	67.8	57.7	60.0	54.8	59.5	60.6	58.5	60.6	57.4	66.5	62.3	66.6	66.0	66.2
1979	67.8	58.6	58.9	54.6	59.8	60.7	58.3	60.2	57.3	65.4	61.8	66.1	64.5	66.2
1980	68.0	57.6	58.7	55.5	59.2	60.3	58.1	59.4	57.9	67.7	63.3	67.0	64.4	66.1
1981	67.8	58.1	61.4	55.9	60.2	61.4	57.6	61.2	58.1	68.0	64.3	68.0	66.4	66.7
1982	56.2	56.4	58.6	52.5	58.1	59.2	55.2	58.8	57.1	65.5	61.4	64.9	62.1	64.2
1983	64.7	58.2	59.0	53.3	59.8	59.0	60.6	60.7	60.1	68.9	62.9	66.4	64.1	66.6
1984	64.1	57.4	58.7	55.3	60.1	60.5	58.8	61.0	58.4	68.5	65.0	66.1	66.6	66.9
1985	63.3	55.8	57.2	53.5	58.6	57.6	57.2	58.4	58.3	67.0	62.4	66.4	65.1	64.9
Year	Bakersfield	Berkeley	Oakland	Mount Hamilton	Los Gatos	San Jose	Salinas	Paso Robles	Santa Maria	Los Angeles	Claremont PC	San Bernardino	Redlands	Riverside

Table 2

Decade Average Temperature at 74 Stations in California

Station	County	Lat dd.mm	Long ddd.mm	Elev Feet	Decade Average Tempemperature Ending Year 1925	1935	1945	1955	1965	1975	1985	Regression Coef. A	B	r
Auburn	Placer	38.54	121.04	1397	59.5	60.3	60.8	59.6	60.2	60.0	60.0	57.96	.001	.05
Bakersfield	Kern	35.25	119.30	495	63.5	64.3	65.0	64.5	64.7	66.1	66.3	-16.78	.042	.91
Berkeley	Alameda	37.52	122.15	345	56.4	56.6	57.2	56.9	57.1	57.0	57.5	29.03	.014	.84
Blythe	Riverside	33.37	114.36	268	69.9	70.9	71.3	72.4	71.8	71.5	71.7	21.78	.025	.69
Chico	Butte	39.40	121.50	205	60.4	61.3	61.1	60.3	61.2	61.1	60.9	52.52	.004	.23
Claremont PC	Los Angeles	34.06	117.43	1201	61.5	62.2	62.1	62.0	62.8	62.2	62.9	28.03	.018	.79
Clousa	Colusa	39.10	122.00	60	60.2	61.0	61.4	60.9	61.1	60.9	61.4	39.34	.011	.59
Cloverdale	Sonoma	38.46	122.59	320	58.9	59.8	60.9	59.7	60.0	59.1	60.0	52.79	.004	.12
Colfax	Placer	39.06	120.58	2418	58.3	58.7	58.9	58.4	59.5	59.1	58.5	44.81	.007	.36
Crescent City	Del Norte	41.46	124.12	40	52.7	53.6	54.2	52.2	52.9	52.6	53.4	61.46	-.004	.14
Cuyamaca	San Diego	32.59	116.35	4650	52.2	53.2	53.6	52.3	53.0	53.1	53.2	37.58	.008	.33
Davis	Yolo	38.32	121.46	60	59.7	59.8	60.4	59.9	60.1	60.0	60.2	48.84	.006	.51
Denair	Stanislaus	37.34	120.47	137	59.8	60.2	61.3	60.2	60.5	59.2	59.7	81.77	-.011	.36
DeSabla	Butte	39.52	121.37	2713	54.7	55.2	55.8	54.9	55.8	55.1	54.5	60.73	-.003	.12
East Park Res	Colusa	39.22	122.31	1205	58.1	58.4	59.4	58.6	58.7	58.3	58.3	60.61	-.001	.05
Electra	Amador	38.20	120.40	715	60.1	60.8	61.2	60.8	60.6	60.2	60.3	68.95	-.004	.23
Elsinore	Riverside	33.40	117.20	1285	63.9	63.5	64.0	63.0	63.3	63.4	65.2	42.81	.011	.32
Escondido	San Diego	33.07	117.05	600	60.6	61.1	61.9	60.9	62.1	62.4	64.0	-28.91	.046	.87
Eureka	Humboldt	40.48	124.00	60	51.3	52.0	52.8	51.6	52.3	51.8	53.2	18.63	.017	.55
Fort Bidwell	Modoc	41.51	120.00	4498	48.0	48.8	48.3	48.0	48.0	48.2	47.6	66.98	-.010	.57
Fresno	Fresno	34.46	119.43	328	63.1	63.7	63.7	62.4	62.3	62.5	63.9	72.86	.005	.16
Glenville	Kern	35.44	118.40	3500	54.0	55.2	55.2	53.3	54.3	54.2	55.0	53.76	.000	.01
Hanford	Kings	36.20	119.40	242	61.9	62.8	62.2	61.4	62.1	61.6	61.6	85.68	-.012	.55
Healdsburg	Sonoma	38.37	122.52	102	58.0	58.6	59.4	58.4	59.9	60.4	61.2	-36.24	.049	.91
Hetch Hetchy	Tuolumne	37.57	119.47	3870	53.0	53.8	53.7	53.2	53.4	53.1	53.2	61.02	-.004	.28
Huntington La	Fresno	37.14	119.13	7020	43.2	44.2	44.1	43.4	43.9	44.2	44.7	13.93	.015	.65
Imperial	Imperial	32.51	115.34	-64	71.1	71.7	72.3	72.4	73.1	73.1	73.8	-9.19	.042	.98
Indio	Riverside	33.44	116.15	11	72.9	73.2	72.9	72.6	73.5	73.2	73.3	60.50	.006	.46
Lemon Cove	Tulare	36.23	119.02	513	62.3	62.6	64.2	63.2	63.2	62.4	63.1	56.02	.004	.12
Lindsay	Tulare	36.11	119.04	385	62.0	62.5	63.1	61.4	62.1	62.2	62.3	67.12	-.003	.10
Livermore	Alameda	37.40	121.46	480	58.4	58.7	59.3	58.5	58.4	58.8	59.6	38.57	.010	.48
Los Angeles	Los Angeles	34.03	118.14	257	62.9	63.9	64.1	63.8	65.2	65.5	66.9	-49.19	.058	.94
Los Gatos	Santa Clara	37.14	121.58	365	58.0	58.5	58.8	58.1	59.5	58.9	59.3	21.02	.019	.73
Mariposa	Mariposa	35.05	119.23	675	65.0	65.5	66.4	65.7	65.7	64.4	64.3	100.20	-.018	.51
Mc Cloud	Shasta	41.16	122.08	3300	48.8	50.0	50.1	48.3	49.3	49.2	50.2	36.85	.006	.19
Merced	Merced	37.19	120.29	170	60.8	61.5	61.3	60.9	61.7	62.0	61.5	36.95	.013	.63
Mount Wilson	Los Angeles	34.14	118.04	5709	55.2	56.2	56.2	54.9	55.3	55.2	56.5	48.66	.004	.12
Mt Hamilton	Santa Clara	37.20	121.39	4206	52.9	53.8	53.5	52.7	53.9	54.3	54.6	8.29	.023	.72
Mt Shasta City	Shasta	41.19	122.19	3544	49.3	48.8	50.1	49.2	49.9	49.5	49.2	43.14	.003	.16
Napa	Napa	38.17	122.16	60	56.8	57.2	58.5	57.8	58.4	58.7	59.8	-24.92	.043	.91
Nevada City	Nevada	39.15	121.02	2781	52.8	53.6	53.6	52.4	52.5	52.2	54.4	46.79	.003	.09
Oakland	Alameda	37.44	122.12	6	56.1	56.5	57.1	56.5	57.7	57.3	58.8	-14.77	.037	.89
Ojai	Ventura	34.27	119.14	750	60.9	61.3	60.9	61.3	62.3	61.2	61.6	38.32	.012	.53
Orland	Glenn	39.45	122.12	254	62.0	62.6	62.7	61.0	61.3	61.4	61.5	98.79	-.019	.62
Paso Robles	San Luis Ob	35.38	120.41	700	58.2	58.6	59.0	58.6	59.2	58.7	59.9	20.48	.020	.77
Petaluma	Sonoma	3[illegible].14	122.38	27	56.5	57.5	58.0	57.2	57.7	57.7	58.0	27.51	.015	.67
Placerville	El Dorado	38.44	120.48	1890	55.3	54.8	55.7	55.1	55.8	56.1	56.5	11.63	.023	.82
Porterville	Tulare	36.04	119.01	393	62.4	62.9	63.5	62.4	63.4	63.5	64.3	15.72	.024	.77
Red Bluff	Tehama	40.09	122.15	342	62.0	62.8	62.7	62.4	62.9	62.5	63.5	34.06	.015	.68
Redlands	Riverside	34.03	117.11	1318	62.4	62.7	62.4	62.2	64.6	63.5	64.6	-9.43	.037	.77
Riverside	Riverside	33.57	117.23	840	63.3	63.1	63.7	62.1	64.0	64.2	65.3	4.32	.030	.68
Sacramento	Sacramento	38.35	121.30	25	60.0	60.5	61.4	60.7	61.5	62.5	63.2	-34.26	.049	.93
Salinas	Monterey	36.40	121.36	69	55.7	56.3	57.2	57.0	57.6	57.0	57.8	0.39	.029	.86
San Bernardio	San Bernar	34.08	117.16	1125	62.9	63.5	63.5	63.7	64.6	64.7	66.4	-33.56	.050	.93
San Diego	San Diego	32.44	117.10	13	61.1	61.7	62.8	62.5	63.6	63.3	66.0	-67.57	.067	.91
San Francisco	San Francis	37.46	122.26	75	56.6	57.2	57.3	56.0	57.1	56.5	57.8	42.96	.007	.26
San Jacinto	Riverside	33.47	116.58	1560	62.7	62.9	62.7	61.4	62.9	63.2	64.0	30.01	.016	.47
San Jose	Santa Clara	37.21	121.54	67	57.4	58.1	59.5	59.0	60.0	59.4	59.8	-12.89	.037	.84
San Luis Obispo	San Luis Ob	35.18	120.40	315	58.7	59.1	59.2	58.5	59.4	58.3	59.9	43.65	.008	.31
Santa Cruz	Santa Cruz	36.59	122.01	130	56.6	57.0	57.6	56.0	56.8	56.5	57.5	50.57	.003	.12
Santa Maria	Santa Barb.	34.54	120.27	254	56.2	57.1	57.9	56.5	56.9	56.6	58.2	29.13	.014	.42
Santa Rosa	Sonoma	38.27	122.42	167	56.2	57.0	58.3	56.6	57.4	58.4	58.5	-3.96	.031	.73
Sonora	Tuolumne	37.59	120.23	1749	59.1	60.4	60.2	58.4	59.5	57.6	58.0	126.06	-.034	.69
Spaulding	Nevada	39.20	120.38	5120	48.5	47.0	48.5	46.8	48.1	47.2	48.1	56.12	-.004	.13
Stockton FS	San Joaquin	38.00	121.19	12	59.6	60.0	59.6	59.4	60.0	60.2	60.8	27.11	.017	.75
Tejon Ranch	Kern	35.02	118.45	1425	64.2	65.3	64.2	62.5	63.7	63.2	63.6	109.20	-.023	.57
Tustin Irvine	Orange	33.44	117.47	118	60.6	62.6	61.7	61.1	62.3	61.9	63.3	10.96	.026	.62
Ukiah	Mendocino	39.09	123.12	623	57.0	58.2	59.0	59.0	59.2	59.2	59.7	-13.16	.037	.89
Vacaville	Solano	38.22	121.57	105	59.1	59.9	60.5	60.0	61.1	60.1	60.6	21.74	.020	.67
Visalia	Tulare	36.20	119.18	354	62.4	63.6	64.3	63.7	63.4	62.7	63.2	65.42	.001	.04
Weaverville	Trinity	40.44	122.56	2050	53.0	53.7	53.8	52.3	53.0	52.5	53.2	71.22	-.009	.36
Willows	Glenn	39.32	122.12	140	61.0	61.6	61.9	60.9	61.2	60.9	61.3	69.64	-.004	.24
Yreka	Siskiyou	41.23	122.38	2625	50.5	51.8	52.3	51.0	52.0	51.8	51.6	30.62	.011	.37
Yuma	Imperial	32.40	114.36	194	71.8	72.3	73.2	73.9	74.5	72.8	74.7	-3.49	.039	.77
	Average				58.68	59.29	59.68	58.88	59.57	59.32	59.98	32.48	.014	.52

Bold type indicates urban stations

JDG - 2/15/87

Table 4

Popluation Calif Counties

County	Y	X	R
Colusa	-127	0.0071	0.94
Alpine	-28.8	0.015	0.86
Sierra	-28.95	0.0161	0.69
Modoc	-56	0.0328	0.57
Madera	-1738	0.091	0.96
Mono	-236	0.123	0.88
Mariposa	-269	0.1412	0.88
Trinity	-326	0.1704	0.95
Glenn	-337	0.181	0.96
Lassen	-369	0.197	0.89
Plumas	-375	0.1983	0.96
Inyo	-378	0.2	0.97
Amador	-400	0.21	0.85
Del Norte	-523	0.274	0.94
Calaveras	-548	0.29	0.9
San Benito	-558	0.294	0.93
Siskiyou	-594	0.32	0.97
Tuolumne	-915	0.478	0.91
Tehama	-934	0.49	0.96
Lake	-1141	0.5936	0.89
Yuba	-1404	0.734	0.99
Sutter	-1428	0.747	0.99
Nevada	-1475	0.77	0.87
Imperial	-1483	0.795	0.94
Mendocino	-1515	0.8	0.97
Kings	-1830	0.9622	0.99
Humboldt	-2496	1.32	0.96
Napa	-2694	1.41	0.98
El Dorado	-2800	1.45	0.9
Yolo	-3368	1.76	0.97
Placer	-3470	1.81	0.94
Shasta	-3578	1.86	0.96
Butte	-3741	1.96	0.96
Merced	-3859	2.02	0.98
San Francisco	-4272	2.33	0.7
San Luis Obispo	-4854	2.53	0.95
Santa Cruz	-5493	2.86	0.95
Tulare	-6262	3.29	0.99
Marin	-6736	3.51	0.98
Solano	-7153	3.73	0.97
Stanislaus	-7728	4.03	0.98
Sonoma	-8574	4.47	0.95
Santa Barbara	-9209	4.8	0.97
Monterey	-9245	4.82	0.99
San Joaquin	-9678	5.07	0.99
Kern	-0.000124	6.48	0.99
Fresno	-0.000136	7.15	0.98
Ventura	-0.000176	9.12	0.94
San Mateo	-0.000196	10.17	0.98
Contra Costa	-0.000215	11.2	0.98
Riverside	-225	11.69	0.95
Sacramento	-0.000248	12.93	0.98
Alameda	-0.000258	13.6	0.99
San Bernadino	-0.0003	15.67	0.97
Santa Clara	-0.000427	22.16	0.96
San Diego	-0.00062	32.24	0.97
Orange	-0.00066	34.48	0.93
Los Angeles	-0.0000217	113.52	0.99
State	0.0000701	365.8	0.99

III. APPENDICES

AGENDA
FOURTH ANNUAL PACLIM WORKSHOP
Asilomar Conference Center
Pacific Grove, CA
March 22, 1987, through March 26, 1987

Sunday, 22 March 1987
1500 - Registration and check-in
1700 - Overview of Workshop Plans
1800 - DINNER
2000 - Wine and Cheese Party; REVIEW TIME SERIES VOLUME DRAFT

Monday, 23 March 1987
0730 - BREAKFAST
0845 - **Workshop was formally convened.**
0900 - Presentations
Session monitor Jim Gardner, USGS-Menlo Park, CA (morning session)

Introductions were made from all attending participants.

Mark Meier, Director, INSTAAR, University of Colorado, informed us of the interest nationally and internationally with regard to climate studies. He suggested that proposals be made for funding of this project to outside interest groups.

Gary Sharp, consultant, Florida, showed a time lapse 9-month film obtained via satellite of the northern hemisphere weather patterns in 24-hour increments.

Tom DeVries, University of Oregon, ask anyone interested in contributing the ELNAR (El Niño in the Ancient Record) Circular to let him know.

David Rea, National Science Foundation, talked about NSF's interest in the PACLIM but alluded that funds were extremely tight for future funding.

1200 - LUNCH
1330 - Session monitor Jurate Landwehr, USGS-Reston, VA (afternoon session)

Paul Sund: NOAA-MFS	A rainfall climatological index based on principal component analyses of data from near coastal stations in Oregon and California
Roger Anderson University of New Mexico	Oxygen minimum zone off Northern California
Linda Heusser New York University	Implications of Pacific climate change along the Northeastern Pacific coast
Alejandro Pares-Sierra State University	Pacific Basin-wide atmospheric-ocean Florida numerical simulation experiments

Larry Benson USGS-Colorado	Changes in the Great Basin hydrologic cycle for the past 30,000 years
Lonnie Thompson The Byrd Polar Research Ctr. Ohio State University	Record of climatic variability from the tropical Quelccaya Ice Cap, Peru, and the Dunde Ice Cap, China, with emphasis on ENSO events
Ray Turner USGS-Arizona	Sonoran desert vegetation dynamics
Lisa Wells Ph.D candidate Stanford University	Marine geology and El Niño events
Julio Betancourt Arizona	Stream flow in southern Arizona during El USGS-Niño years

Tuesday, March 24, 1987

0730 - BREAKFAST
0845 - Start session
0900 - Presentations
Session monitor Sus Tabata, Inst. of Ocean Sciences, Canada (morning session)

Richard Schwartzlose Scripps Inst. of Oceanography	Climate influence on large-scale fisheries variations
Dan Cayan Inst. of Oceanography	Large-scale atmospheric circulation and Scripps stream flow, western North America
Maurice Roos Dept. of Water Resources	Possible changes in California snowmelt CA runoff patterns
James Slack USGS-Menlo Park, CA	Long-term variability in United States stream flow anomalies
Kozo Takahashi Hole Oceanographic Institution	Climatic response os siliceous plankton Woods fluxes in the Gulf of Alaska
Arndt Schimmermann Scripps Inst. of Oceanography	Evidence of climate variability in marine sediments
Richard Casey University of San Diego	Different kinds of California El Niños, from recent and fossil records of the Southern California Sea
Julio Betancourt USGS-Arizona	Long-term vegetation history of southwestern United States from fossil pack rat middens

Roy Walters USGS-Tacoma, WA	Glacial budget time series

1200 - LUNCH
1330 - **Afternoon session was held at the Monterey Aquarium Auditorium**

Presentations: Session monitor Larry Breaker, Moss Landing Marine Lab.

Jerome Namias Scripps Inst. of Oceanography	The quest for understanding and prediction of some short-period climatic fluctuations
John McGowan Scripps Inst. of Oceanography	Climate and chlorophyll a: long-term trends in the Central North Pacific
Richard Barber Duke University Marine Lab.	Climate variability and large-scale primary productivity variability
Gary Sharp Gainesville, FL	Long- and short-term climate patterns and processes in fisheries systems
Richard Parrish Pacific Environmental Group	Climate variability and the higher trophic levels

1800 - DINNER
Evening session was devoted to informal discussion groups

Wednesday, 25 March 1987
0730 - BREAKFAST
0845 - Start Session
0900 - Discussion and Presentations

Session monitored by John McGowan

David Adam USGS-Menlo Park, CA	Climate records in California lake sediment
Robert Curry Santa Cruz, CA	Climate variability in the Geologic Record
Nicolas Grijalva SARH-Mexico	Available data record from Mexico

1200 - LUNCH
1330 - (working groups)
1800 - DINNER - BBQ
2000 - EDITORAL BOARD MEETING and WORKING GROUPS

Thursday, 26 March 1987
0730 - BREAKFAST
0845 - start session
0900 - Discussion of status of publications, future plans, etc.

Session monitor Mark Meier, INSTAAR, Colorado

A PACLIM statement developed by the Editorial Board members present and written by Dan Cayan and Jurate Landwehr was read to the members by Mark Meier. Comments and/or deletions and corrections were noted.

How to define limits of endeavor:
(1) The data sets have to relate to the whole
(2) Data sets must compliment each other
(3) Data sets must be amendable to synthesis

It was suggested that we include the western coast of South America and western America's in the title wording.

Very few contributions have come from the Polar region. These should be courted. However, the Antarctic should be included only as it relates to the Pacific.

1200 - **WORKSHOP WAS ADJOURNED**

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